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Spectrochemical Analysis of Steelmaking Slags

By C. Georg Carlsson and John T. M. Yü

SYNOPSIS

A procedure is described for the determination of lime/silica ratio of open-hearth and electric-furnace slags and for the complete analysis of such slags. The sample is mixed with graphite powder and pressed into a briquette, which is subjected to a low-tension arc-like triggered spark for excitation. The actual percentages of the oxides are calculated using a 'mutual standard method.' The accuracy compares favourably with routine chemical analysis, and the time necessary for a complete analysis is only about half an hour. Complete details of the method are given.

Introduction

SPECTROCHEMICAL analysis of non-conducting powders has been used for many years in several branches of science for the determination of trace elements and for qualitative or semi-quantitative work. The method employed has almost universally been the D.C.-arc excitation of the powder in a cupped graphite or carbon electrode. Only in recent years has the quantitative determination of the main constituents of non-conducting powders been investigated. The pioneer work was carried out on fairly homogeneous products such as metallurgical slags and cement. Two different methods have been used :

(1) The arc method, already mentioned, with modifications to give greater accuracy

(2) A briquetting method in which the sample, mixed with suitable substances, is pressed to a firm briquette which is then analysed by spark excitation using procedures similar to those developed for metallic specimens.

The arc method with the sample mixed with graphite to give a smoother evaporation has been used by Smith and Hoagbin[1] for the analysis of ceramic materials, by Rosza[2] for open-hearth slag, and by Hasler, Harvey, and Barley[3] for cement and other mineral products. Kvalheim[4] added strontium carbonate and graphite when analysing minerals and rocks. An addition of copper oxide has been tried by Korzh[5] for open-hearth slags, and by Jaycox[6] for ceramic materials. Nickel oxide was used by Oshry, Ballard, and Schrenk[7] and different mixtures of oxides, carbonates, etc. by Carlsson,[8] Helz[9], and others. To get a more uniform evaporation Harrison and Ralph[10] and Fitz and Murray[11] pressed small pellets of the sample with suitable additions and used these pellets in place of loose powder in cupped electrodes.

Powder in cupped electrodes with a high-tension spark instead of arc excitation has been tried by Steinberg and Belic[12] and Milbourne and Hartley.[13] Woodruff[14] used a similar procedure with a triggered low-tension spark (Multisource). To avoid too rapid blowing away of the sample by the spark, Steinberg and Belic cemented the sample particles together with cellulose varnish. Loose powder on a flat graphite electrode and excitation by a high-tension spark were tried by Eeckhout.[15]

The other method, the sparking of briquettes, has been used by several investigators. In the earliest procedures the high-tension spark was used for excitation by the Applied Research Laboratories,[16] by Dietert,[17] and by Churchill and Russell,[18] but later Terry,[19] Helz and Scribner,[20] Hasler, Harvey, and Barley,[3] and Zander and Terry[21] used a triggered low-tension spark, the Multisource, which is more arc-like and has given better results. In early work,[16, 17] metallic powder (Fe) was used as binding material, but better results were later obtained with a special kind of flaky graphite. For analysing mineral products which show large differences in crystal form, a fluxing medium (often Li_2CO_3) is added. Frequently an internal standard element, such as cobalt as cobalt oxide,[3, 21] is added at the same time. Hasler and Harvey[22] have recently introduced a method of sparking wheel-shaped briquettes by rotating them and sparking to the edge.

The fused-salt method which does not fall into either of the above classes has been employed by Nachtrieb, Johnson, and Dress,[23] and by Irish.[24]

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Mr. Carlsson and Mr. Yü are at the Metallografiska Institutet, Stockholm.

This survey of the literature shows that a variety of spectrochemical analysis has been tried : in most cases a satisfactory accuracy has been reported. In the present investigation, the D.C.-arc method was tried initially, but the results obtained were not encouraging, and the briquette method with a low-tension triggered spark was later used. Accuracy, speed, and simplicity were satisfactorily obtained with this method and no alternative was tried.

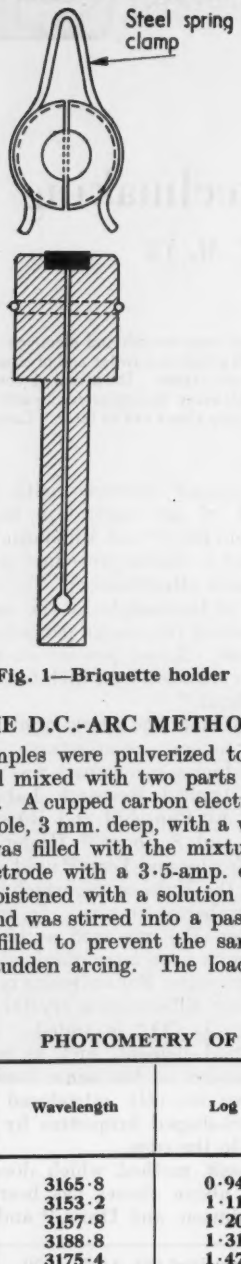

Fig. 1—Briquette holder

THE D.C.-ARC METHOD

The slag samples were pulverized to pass a 100-mesh sieve and mixed with two parts by weight of carbon powder. A cupped carbon electrode having a 2·5-mm. dia. hole, 3 mm. deep, with a wall thickness of 0·5 mm., was filled with the mixture and arced as positive electrode with a 3·5-amp. current. The powder was moistened with a solution of varnish in amyl acetate and was stirred into a paste before the electrode was filled to prevent the sample blowing away by the sudden arcing. The loaded electrode was heated to 150° C. to expel moisture, and the sample particles were thus cemented together. With this procedure the loss of sample at the start of the arc was minimized, and a successful evaporation within an arcing time of 75 sec. was obtained.

An investigation of the excitation of silicon and calcium during different periods of arcing, by moving the plate every 5 sec., showed that the silicon lines were weak compared with the calcium lines in the early part of the burning time, and stronger towards the end. The more sample left at the end of the exposure, the weaker will be the silicon lines relative to the calcium lines. It is therefore necessary to evaporate the sample completely.

Many tests were carried out using the arc method. Working curves were prepared from seven chemically analysed samples, and reproducibility tests were made. The reproducibility was not satisfactory, and the working curves shifted from time to time. The causes of these poor results are probably :

(1) Loss of sample occurring at the start of the arc (in spite of cementing the powder with varnish)
(2) Non-uniform evaporation during arcing
(3) Slight variation in the amount of sample loaded into the electrode ; weighing was considered too time-consuming
(4) An inherent inaccuracy in the D.C. arc owing to wandering of the arc and to varying self-absorption.

The influence of factors 1, 2, and 3 is apparent from the appreciable variation in the total time required for burning the samples completely.

THE BRIQUETTING METHOD

PROCEDURE

Preparation of Sample

If necessary, a preliminary crushing of the slag was carried out by hand in an iron mortar until the particles passed a 20-mesh sieve. The samples were then ground in a motor-driven agate mortar until about 99% of the powder passed a 100-mesh sieve. During the successive steps of grinding and sieving, particles of metallic iron were removed by means of a magnetic pin. When only a small quantity of powder, sufficient for one analysis, was required, the crushing was carried out more rapidly in an iron mortar. A few lumps of the slag weighing about 1 g. were crushed until about half passed a 100-mesh sieve ; this half was used for making pellets. Tests have shown that if the slag is homogeneous no error is introduced by this incomplete crushing. Samples containing free lime deserve careful attention.

Table I

PHOTOMETRY OF IRON SPECTRA FOR PLATE CALIBRATION

No. of Line	Wavelength	Log I	Difference Log I	Galvanometer Deflections		
				(1)	(2)	Mean
1	3165·8	0·944	0	200	199	199·5
2	3153·2	1·111	0·167	178	177	177·5
3	3157·8	1·200	0·256	164	163	163·5
4	3188·8	1·311	0·367	145	145	145·0
5	3175·4	1·477	0·533	118	117	117·5
6	3239·4	1·955	1·011	52·5	53	52·75

Preparation of Briquettes

The sample is mixed with an equal part by weight of Special Spectroscopic Graphite Powder, Grade SP–1 (National Carbon Company, Cleveland, Ohio) by shaking by hand in a glass bottle (approx. 25-ml. capacity) containing 8–10 steel balls of different diameters. The time of shaking depends on the amount being mixed. With 1 g. of mixture, which is sufficient for three briquettes, a thorough mixing is obtained in about 2 min. Between different samples the bottle and steel balls are cleaned by shaking two or three times with coarse sand. This method of mixing, which has been used by Smith and Hoagbin,[1] is much superior to grinding in an agate mortar, in regard to both thoroughness and time.

The briquettes are pressed in a 7-mm. dia. mould at a total pressure of 3800 kg. The steel surfaces in contact with the briquette are given a good finish to produce smooth briquettes. The pressure used is high enough to give the briquette a good mechanical strength, but the structure is still sufficiently loose to permit an appreciable penetration by the spark. For each briquette approx. 300 mg. of mixture is used giving a 7-mm. dia. briquette with a thickness of 2·8 mm. A simple holder for the briquette is shown in Fig. 1.

The Spectrogram

The briquette is used as the upper, negative electrode, and a high-purity graphite rod as the lower electrode. The graphite rod is sharpened to a 120° conical point in a motor-driven electrode cutter. The electrode spacing is 3 mm. The triggered low-tension spark is generated with the Emitator source unit[25] (*see* Appendix) with the following settings :

Capacitance	30 μF.
Added inductance	0·05 mH.
Total inductance (measured)	0·14 mH.
Added resistance	1 ohm
Total resistance (measured)	1·5 ohms
Input (main circuit)	220 V. (D.C.)
Input (triggering circuit)	220 V. (A.C.)
Number of sparks/sec.	100
Primary resistance	70 ohms
Primary current	approx. 3·1 amp.

The current in the discharge circuit, measured with a radio-frequency ammeter, is about 4·9 amp. The discharge consists of a unidirectional flow of electricity, since no oscillations occur at the low voltage used.[25] The spectrograms obtained are of an arc-like character.

The spectrograms are recorded with a Hilger large quartz spectrograph set for the wavelength region 3500–2500 Å. with a slit width of about 10μ. With Ilford Thin-Film Half-Tone plates a suitable density is obtained in an exposure time of 60 sec. (no pre-spark).

Processing

The plates are developed in a metol-hydroquinone developer for 4½ min. at 19° C., rinsed in running water and fixed for 10 min. After washing under running water for about 10 min. the plates are dried in hot air from a hair-drier. If a short total time of analysis (30 min.) is required the processing time can be appreciably reduced.

Density Measurement and Plate Calibration

The microphotometer used gives a magnification of 22 dia. The slit is 15 mm. long and 0·25 mm. wide, giving the measured area of the plate as 0·008 sq. mm. By varying a resistance in the lamp circuit the clear-plate reading is adjusted to 220. The full-scale deflection of the Multiflex galvanometer is 200, and the sensitivity of the instrument is reduced to one tenth when the clear-plate reading is taken.

The characteristic curve of the plate is determined using iron lines of known intensity according to Dieke (Carlsson[26]). Using a pair of pure iron bars the spectrum of iron is recorded in duplicate in the central part of each plate, and six selected iron lines from the 3200 Å. group are measured. On a calculating board[26] the microphotometer readings are plotted against the log intensity of the lines ; this gives the characteristic curve of the plate. Details of the procedure are given below and an example is shown in Table I.

Excitation source	Emitator, interrupted D.C. arc
Number of ignitions/min.	100
Duration of each ignition	0·1 sec. (setting 25)
Variable resistance	40 ohms
Exposure time	17 sec.

Intensity-Ratio Determination

Using the calculating board and the characteristic curve of the plate, the intensity ratios are determined. Silicon serves as the internal reference element, and the ratios between the lines of all other elements and the silicon line are determined. A typical example of the conversion of the microphotometer readings into

Table II

THE MICROPHOTOMETRY AND DATA CONVERSION OF SLAG SAMPLES ANALYSED FOR LIME/SILICA RATIO

Sample No	Si 2987		Ca 2995		Log-Intensity Ratio		Mean Log-Intensity Ratio
	(1)	(2)	(1)	(2)	(1)	(2)	
IV	64·5	64	124	121	−0·435	−0·42	−0·43
8522:3	92	109	118	142	−0·165	−0·196	−0·18
IX	80	93	99	115·5	−0·141	−0·141	−0·14
7909:9	159	148	160	146	−0·006	0·013	0·004
X	159	160	132	132	0·17	0·178	0·17
8066:2	171	166	143	135	0·199	0·209	0·20
8066:4	164	150	130	111	0·223	0·234	0·23
7962:2	162	160	117	112·5	0·283	0·294	0·29

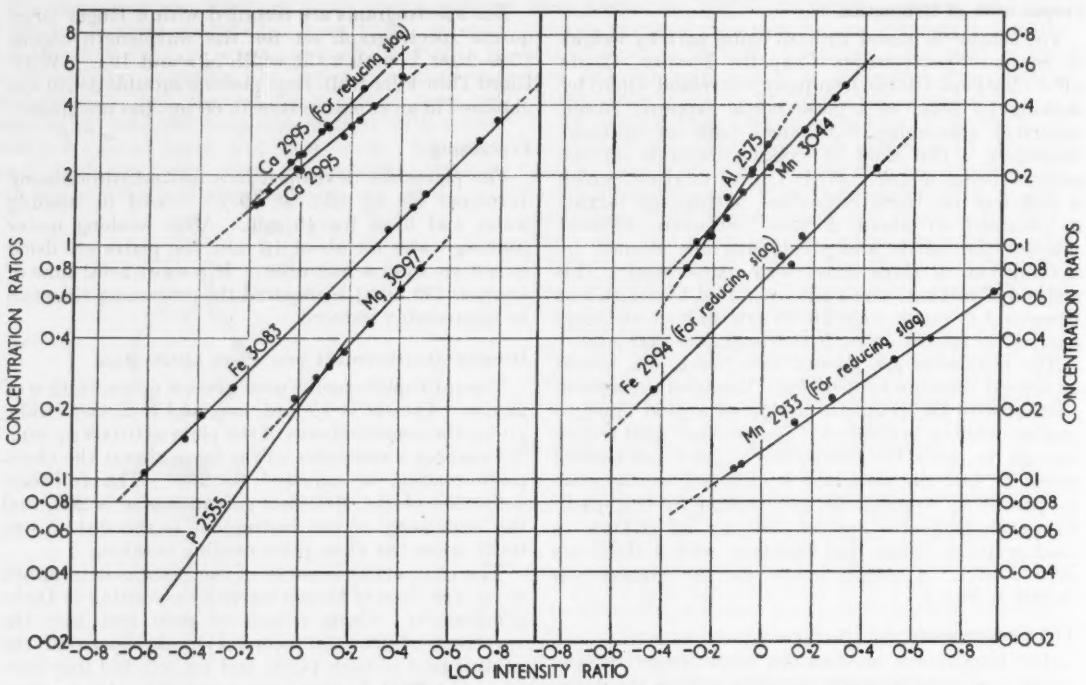

Fig. 2—Analytical curves for the principal and minor components in slags (internal reference line Si 2987·65 for Ca, Fe, Mn, Mg, and Al, and Si 2532·38 for P)

Table III

LINE-PAIRS

Oxidizing Slags	Reducing Slags
Al 2575·10/Si 2987·65	Al 2575·10/Si 2987·65
Ca 2994·96/Si 2987·65	Ca 2994·96/Si 2987·65
Ca 3009·21/Si 2987·65	
Fe 3083·75/Si 2987·65	Fe 2994·43/Si 2987·65
Mg 3096·92/Si 2987·65	Mg 3096·92/Si 2987·65
Mn 3044·57/Si 2987·65	Mn 2933·06/Si 2987·65
P 2554·93/Si 2532·38	
Ti 3088·03/Si 2987·65	Ti 3088·03/Si 2987·65

intensity ratios is given in Table II for the determinations of lime/silica ratios in eight slag samples.

Analytical Curves and Method of Calculation

The absence of a component, occurring in equal quantity in all samples, which could be used as an internal standard element, is a severe handicap. The addition of a suitable reference element is inconvenient and would probably introduce an additional source of error. In this work, silicon is used as the internal element, but another element, for instance calcium, could be used, although silicon has the special advantage that the lime/silica ratio, which is of first interest, can be read directly from the curve.

Table IV

CALCULATION OF THE STANDARD DEVIATION FROM REPEAT DETERMINATIONS OF LIME/SILICA RATIO

Repeat Runs	Slag IV	Slag 8522:3	Slag IX	Slag 7909:9	Slag X	Slag 8066:2	Slag 8066:4	Slag 7962:2
1	0·94	1·59	1·67	2·19	3·09	3·25	3·39	3·83
2	0·96	1·50	1·67	2·15	3·10	3·27	3·48	3·91
3	0·93	1·54	1·70	2·38	3·03	3·32	3·49	3·97
4	0·98	1·47	1·72	2·29	3·00	3·29	3·49	3·95
5	1·02	1·50	1·57	2·29	3·11	3·19	3·49	3·90
6	...	1·45	1·62	2·30	3·03	3·20	3·49	3·77
Mean	0·966	1·51	1·66	2·27	3·06	3·25	3·47	3·89
Max.	1·02	1·59	1·72	2·38	3·11	3·32	3·49	3·97
Min.	0·93	1·45	1·57	2·15	3·00	3·19	3·39	3·83
Standard deviation ±	0·036	0·050	0·055	0·083	0·045	0·051	0·040	0·067
% ±	3·7	3·3	3·3	3·7	1·5	1·6	1·2	1·7

Analytical curves are prepared by plotting intensity ratios as the abscissa, and the concentration ratios, calculated from chemical figures, as the ordinate, using a log scale. Figure 2 shows such curves which have been prepared from the average log-intensity ratios of duplicate determinations of 14 chemically analysed slag samples repeated over a series of plates. The curves are found to be quite stable and it is unnecessary to check them against standard samples on each plate.

Since the silicon content of the samples varies, and since silicon is one of the constituents to be determined, a special method of calculation must be used. The ' mutual standard method ' described by Churchill and Russell[18] has been adopted with satisfactory results.

From the working curves, the ratios

$$\frac{\%\ CaO}{\%\ SiO_2},\ \frac{\%\ FeO}{\%\ SiO_2},\ \frac{\%\ MnO}{\%\ SiO_2},\ \frac{\%\ MgO}{\%\ SiO_2},\ \text{and}\ \frac{\%\ Al_2O_3}{\%\ SiO_2}$$

are determined. The content of SiO_2 can then be calculated from the relationship

$$\%\ SiO_2 + \%\ CaO + \%\ FeO + \%\ MnO + \%\ MgO + \%\ Al_2O_3 + \%\ \text{undetermined constituents} = 100,$$

or, after transformation, % SiO_2 equals:

$$\frac{100 - \text{undetermined constituents}}{1 + \frac{\%\ CaO}{\%\ SiO_2} + \frac{\%\ FeO}{\%\ SiO_2} + \frac{\%\ MnO}{\%\ SiO_2} + \frac{\%\ MgO}{\%\ SiO_2} + \frac{\%\ Al_2O_3}{\%\ SiO_2}}$$

Undetermined constituents are usually assumed to be 1%. When the value of SiO_2 is known the other constituents are obtained by multiplying the concentration ratios read from the working curves by the percentage of SiO_2.

Choice of Line-Pairs

The choice of line-pairs is based on a consideration of freedom from interfering lines, intensity, intensity/concentration relationship, and proximity to other lines being measured. Table III gives the lines used.

The selection of both calcium and silicon lines is restricted by the fact that most of the possible lines are either too intense or fail to show a favourable intensity/concentration relationship. The application of rotating sectors to bring the intense lines to a measurable density does not give good results. The intensity/concentration relationship for these strong lines is poor, probably because of self-reversal.

The silicon line 2987·65 is used as the internal reference line in all cases except for phosphorus. The two calcium lines 2994·96 and 3009·21 are both equally reliable and give a suitable range of photometer readings. For reducing slags, which are very low in iron and manganese, special stronger lines must be used for these elements.

Difficulty was encountered in the selection of phosphorus lines. This element shows poor spectral sensitivity, and in addition manganese and iron lines may interfere with many of the phosphorus lines. The lines 2136 and 2149 which are recommended by other investigators are very weak in the prism spectrograph used and no better line than 2554·93 has been found. A modified method involving a capacitance of 100 μF. instead of 30 μF., with all other conditions unchanged makes the phosphorus lines stronger, and for an estimation of phosphorus a separate exposure is made. If the P_2O_5 content is found to be over 1% the term ' undetermined constituents ' in the calculation has to be changed. In the ordinary procedure the determination of phosphorus is not included, and only limited data have been collected. The working curve given for phosphorus is thus uncertain.

RESULTS

Reproducibility Test

To test the reproducibility of the method the lime/silica ratio of eight slag samples has been determined over three plates. The samples were run in duplicate on each plate, and the figures listed in Table IV refer to single determinations. The standard (r.m.s.) deviation has been calculated for each sample.

Comparison with Chemical Analysis

The accuracy of the method and its possibilities for steelworks application have been tested by analysing 32 electric-furnace slag samples, and ten open-hearth slag samples obtained from Surahammars Bruks AB. The results are shown in Tables V and VI.

Some of the electric-furnace slags were taken during the refining period, and they show very high lime contents and low iron and manganese contents. It was found that the lime/silica ratios of these slags could not be determined from the curve used for oxidizing slags and a special curve was constructed. This curve has been consulted when the ordinary iron line 3083 and manganese line 3044 are invisible or very weak, and when other lines have to be used for these elements.

Some of the electric-furnace samples contain fluorspar but the fluorine content has been determined in a few cases only. For all samples the total calcium content has been calculated as CaO, and this figure thus includes the fluorspar present. For information the fluorine content is given in the last column of Table V. The chemical analysis values of FeO have been calculated from the total iron content.

The spectrographic results are the average of two, three, or in some cases four or five, spectrograms. The usual procedure is to run duplicates, and a single spectrographic value is the average of two spectrograms. To minimize the effect of random errors three spectrograms were taken of some samples, and in a few cases, where large discrepancies between the chemical and spectrographic results occurred, the samples were re-run and the average taken of all spectrograms. The chemical results are single determinations.

The tables show that chemical and spectrographic values are generally in satisfactory agreement. The chemical check analyses usually do not quite agree with either chemical routine or spectrographic values, but the results cannot be regarded as unfavourable to the spectrographic method. A few samples, however, show quite large discrepancies, *e.g.*, Nos. N671–3 and N671–4, which have an extremely high FeO content. This is not surprising because working curves prepared from standards containing 15–25% of FeO would not be expected to be valid for samples containing about 50% of FeO.

Table V

RESULTS OF SPECTROGRAPHIC AND CHEMICAL ANALYSIS OF ELECTRIC-FURNACE SLAG SAMPLES

Charge	Sample No.	Basicity CaO/SiO_2			SiO_2, wt.-%			CaO, wt.-%			FeO, wt.-%			MnO, wt.-%			MgO, wt.-%			Al_2O_3, wt.-%		F, wt.-%
		Chemical A	Chemical B	Spectrographic	Chemical A	Chemical B	Spectrographic	Chemical A	Chemical B	Spectrographic	Chemical A	Chemical B	Spectrographic	Chemical A	Chemical B	Spectrographic	Chemical A	Chemical B	Spectrographic	Chemical B	Spectrographic	Chemical B
N573	1	1·4		1·3	33·8		35·0	48·0		43·7	3·6		3·7	3·5		3·6	9·1		10·0		2·5	
,,	2	3·2		3·2	14·4		14·6	45·5		46·6	24·0		24·2	4·4		4·6	6·3	7·8	7·1	1·5	1·6	
,, R	3	2·6		2·8	16·6		15·8	42·4		44·6	25·7		24·2	4·2		4·6	5·1	7·6	7·3	1·8	1·7	
,, R	4	4·7		4·7	14·9		15·1	70·0		71·0	4·4	4·1	4·8	0·9		1·0	2·5	3·1	2·7	3·1	3·2	
,, R	5	5·0		5·1	14·8		14·5	74·1		74·2	3·5	3·2	3·2	0·9		0·7	1·1		2·2		1·9	
,, R	6	3·6		3·5	18·7		18·0	68·1		63·0	1·5		1·4	0·8		0·7	3·2		4·2		2·3	
,, R	7	3·2	2·9	2·9	20·7	21·6	22·0	65·2	61·8	64·0	0·8	0·5	0·4	0·1	0·2	0·3	4·2	5·7	6·2	2·9	2·2	9·5
N587	1	2·4		2·7	21·7		20·4	51·4		54·0	9·8		9·6	6·0		5·3	7·7		7·0		1·4	
,,	2	2·5		2·8	19·6		18·4	49·7		50·8	11·8		11·4	5·0		4·4	11·1		11·0		1·8	
,, R	3	2·1	2·1	2·2	12·3	11·5	12·5	25·7	24·6	27·5	42·5	41·6	41·3	7·6	7·1	6·5	9·1	10·8	9·5	1·5	1·9	0·1
,, R	4	3·2	3·2	3·2	19·6	19·6	19·6	63·0	62·7	63·0	3·1	2·2	2·0	2·1	1·7	2·0	4·3	4·3	4·1	5·4	5·3	3·6
,, R	5	3·1		3·0	20·2		20·3	62·2		60·8	2·6	1·7	1·9	2·2		1·7	5·0		6·6		5·5	
,, R	6	2·6		2·6	23·1		23·3	61·1		61·3	1·3		<1·0	0·6		0·4	6·2		6·3		3·3	
,, R	9	2·5		2·5	23·5		24·2	58·0		59·6	1·3		<1·0	0·4		0·1	7·0		7·3		3·6	
N588	1	1·5		1·6	30·8		29·4	46·5		45·6	6·7		5·9	5·2		4·8	10·9		11·2		2·1	
,,	2	3·2		3·3	12·2		13·0	39·4		43·1	31·1		29·0	4·7		4·3	7·4		8·1		2·0	
,, R	3	4·9	3·9	4·5	13·7	17·0	16·2	67·0	66·5	71·9	1·8	1·2	1·2	0·6	0·4	0·5	3·9	3·5	3·9	5·5	4·4	6·8
,, R	4	3·0		3·2	21·4		20·2	65·3		63·9	2·6		1·6	0·5		0·5	6·6		7·4		3·2	
,, R	5	3·0	3·4	3·8	20·9	19·2	18·1	61·5	64·4	67·8	2·1		0·7	0·3		0·3	6·0		6·6		3·0	
,, R	6	4·1	3·3	3·4	16·0	19·4	19·6	65·4	64·2	66·5	2·3	1·0	1·2	0·3	0·3	0·3	5·3	5·2	5·9	1·9	2·5	10·0
N670	1	2·1		2·1	25·1		25·2	52·6		52·8	6·2		6·2	4·6		3·8	8·4		8·2		1·8	
,,	2	2·7		3·0	17·0		16·7	46·6		49·3	19·8		18·9	4·8		4·8	7·6	8·2	6·6	1·8	2·0	
,,	3	2·4		2·7	16·8		16·9	40·0		44·6	26·4		23·1	5·1		4·7	7·2		6·8		2·0	
,, R	4	4·2	4·0	3·9	16·3	17·0	17·7	68·6	68·2	69·1	3·1	1·9	1·2	0·5	0·5	0·7	3·3	3·0	3·2	4·5	6·1	4·9
,, R	6	3·2		3·0	19·9		20·9	63·5		62·6	1·8	0·9	0·7	0·7		0·7	7·0		6·9		3·5	
,, R	7	3·9		3·9	17·1		17·8	65·8		68·6	1·5		0·8	0·5		0·3	5·8		4·6		2·7	
N671	1	2·2		2·4	23·6		22·9	53·0		53·7	10·0		8·7	5·1		4·9	7·8		6·9		1·6	
,,	3	1·9	2·4	2·5	12·2	11·1	13·6	23·0	26·2	33·9	51·5	50·2	41·4	3·8		4·3	3·8		4·5		2·5	
,,	4	2·4	2·5	2·7	12·5	12·1	14·2	30·0	30·9	37·8	45·0	41·4	34·3	3·5		3·8	7·6		7·2		2·1	
,, R	5	2·3		2·2	25·4		26·1	57·4		57·5	1·8		0·6	0·6		0·6	7·5		7·5		4·5	
,, R	7	2·2	2·3	2·3	25·3	25·2	25·1	55·8	57·7	57·9	1·8	0·5	0·7	0·3	0·2	0·3	7·8	8·4	8·4	4·8	4·5	2·6
,, R	9	2·4		2·4	24·1		23·8	58·0		57·0	1·8		0·7	0·3		0·3	11·1		11·0		3·6	

R indicates reducing slag
Chemical A indicates routine analysis from Surahammars Bruks AB.
Chemical B indicates check analysis from the Metallografiska Institutet

Table VI

SPECTROCHEMICAL AND CHEMICAL ANALYSIS OF OPEN-HEARTH SLAG SAMPLES

Sample No.	Basicity CaO/SiO$_2$			SiO_2, wt.-%			CaO, wt.-%			FeO, wt.-%			MnO, wt.-%			MgO, wt.-%			Al_2O_3, wt.-%			TiO_2; wt.-%	P_2O_5; wt.-%
	Chemical A	Chemical B	Spectrographic	Chemical A	Chemical B	Spectrographic	Chemical A	Chemical B	Spectrographic	Chemical A	Chemical B	Spectrographic	Chemical A	Chemical B	Spectrographic	Chemical A	Chemical B	Spectrographic	Chemical A	Chemical B	Spectrographic	Spectrographic	Chemical A
A 3190–1	1·3	1·5	1·4	23·5	24·1	24·4	30·4	36·1	34·2	15·9	16·1	17·0	10·3		10·5	8·6		8·8	10·3	3·1	3·1	~ 0·5	1·7
A 3190–2	1·9		1·9	21·2		22·0	40·6		41·8	14·4		14·1	8·2		7·7	9·8		9·3	6·7		3·1	~ 0·4	1·4
A 3191–1	1·4		1·3	28·0		29·6	38·3		38·5	11·1		11·0	7·6		6·3	10·4		10·7	5·3		1·9	~ 0·4	1·1
A 3191–2	1·6		1·5	26·6		27·0	41·4		40·5	9·3		9·5	8·6		7·8	10·6		11·1	5·1		2·1	~ 0·4	1·1
A 3192–1	2·4		2·5	18·0		18·3	43·5	44·0	46·3	19·1		18·3	6·6		5·9	8·4		7·7	3·8		2·0	~ 0·3	1·2
A 3192–2	1·4		1·5	26·2		26·0	37·8		39·0	13·9		13·5	10·0	9·3	9·1	8·4		8·6	3·9	2·0	1·8	~ 0·4	1·7
A 3193–1	1·3		1·2	27·0		27·9	34·4		33·5	13·9		15·3	9·0		8·4	10·4		10·6	5·1		2·4	~ 0·4	1·7
A 3193–2	1·9		1·9	23·8		24·2	44·1		44·8	9·8		9·9	6·7	6·1	5·8	11·8		11·1	4·5		2·1	~ 0·5	1·3
A 3194–1	1·5		1·5	24·1		25·2	36·8		37·8	15·7		13·9	10·0		9·1	8·9		9·4	5·6		2·6	~ 0·4	1·9
A 3194–2	2·4		2·4	19·7		19·5	46·3		46·9	13·4		13·2	7·4		6·5	9·7		9·4	3·8		2·4	~ 0·4	1·5

Chemical A indicates routine analysis from Surahammars Bruks AB.
Chemical B indicates check analysis from the Metallografiska Institutet

The results indicate that the spectrographic method gives about the same accuracy as routine chemical analysis. This accuracy satisfies the needs of steelworks, and since the spectrographic method is much quicker, it should prove useful as a substitute for chemical analysis, and should make possible the better supervision of the processes in the melting shop.

Acknowledgment

The investigation recorded in this paper was made possible by a special grant from the Research Organization of Jernkontoret, Sweden. A committee has been appointed by that body for the purpose of studying the subject of spectrochemical slag analysis. Its membership is: Mr. C. G. Carlsson, Mr. S. Fornander, and Mr. H. Pettersson.

APPENDIX

Emitator Source Unit

The Emitator source unit was developed in 1945–46 at the Metallographic Institute and is being manufactured by Bolidens Gruvaktiebolag in Sweden. It consists of two units, one for high-tension and the other for low-tension discharges. The high-tension unit (Fig. 3*a*), produces self-igniting high-tension sparks, which can be uncontrolled (free spark) or controlled by means of a rotating interrupter (time-controlled spark) or by means of a fixed gap in series with the analysis gap (tandem spark, voltage-controlled spark). The transformer, rated 2 kVA., gives an effective maximum voltage of 15 kV. The capacitance at this voltage can be varied between 0·005 and 0·020 μF. Variable inductance and resistance are provided.

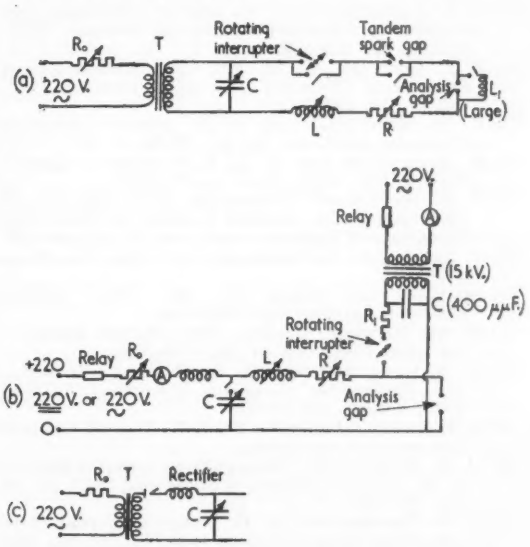

Fig. 3—Circuit diagram for Emitator source unit: (*a*) high-tension unit; (*b*) low-tension unit connected to mains; (*c*) low-tension unit for producing a triggered spark with higher voltage than that of the mains

The low-tension unit (Figs. 3*b* and *c*) consists of a triggering circuit, which gives a time-controlled high-tension spark of low energy for the ignition, and the main circuit which is fed from the mains with 220 V., D.C. or A.C. (Fig. 3*b*), or from a transformer and rectifier with 800 V. D.C. (Fig. 3*c*). By means of relays, continuous or interrupted D.C. or A.C. arcs can be produced, and by connecting the large condenser (1–200 μF. at 220 V.) in the main circuit, low-tension sparks are obtained. The inductance in the main circuit can be varied from a minimum of 0·05 mH. to 2·0 mH. and the resistance R from 0–130 ohms. The triggering circuit gives one spark every half-cycle or every other half-cycle as required. A fuller description of the unit and the principles underlying it has been given by Carlsson and Rynninger.[25]

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Higher Technological Education

The National Advisory Council on Education for Industry and Commerce has recently published its first report entitled "The Future Development of Higher Technological Education."

The main recommendations of the Council are :

(i) The establishment or development of courses of a high standard in technology
(ii) The creation of new awards of degree standard
(iii) The establishment of a Royal College of technologists to approve such courses and confer the awards.

The Council was set up in 1948 by Mr. George Tomlinson, the Minister of Education, under the Chairmanship of Lieut.-Gen. Sir Ronald M. Weeks, to advise him on all matters concerned with the education for industry and commerce, and this report suggests how higher technological education should be developed in this country. The main task of the Council was to suggest how the contribution of the technical colleges could be improved and expanded to meet not only the needs of industry but also those of the individual student. The views of 145 different bodies have been considered by the Council, and in a Foreword to the Report the Minister states that before taking any decision on the recommendations he will welcome and consider any comments made to him.

In addition to the Chairman, the Council consists of 52 representatives of the local education authorities, universities, teachers, employers, and employees, and a further 20 members nominated by the Minister.

At the present time both the universities and the technical colleges are concerned with the training of technologists, the technical colleges dealing more with students coming direct from industry. The Council agrees that the universities have a specific function to perform in the development of technological education and that their work should be more closely related to fundamental science and that of the technical colleges, their courses, in general, containing a smaller amount of training related to immediate or special work in industry.

The contribution of the technical colleges is already considerable. In 1948, 7100 students were taking full-time courses of a degree standard with a further 9784 taking part-time courses. The Council consider that, given a radical improvement in finance, equipment, staffing, and accommodation, these colleges could and should provide more high-level courses of a degree standard and courses for post-graduate work. They also feel that a suitable award is necessary to encourage students to undertake these advanced courses and recommend an Associateship of the suggested Royal College as the first award, Membership for the second award, and Fellowships and Honorary Fellowships for those who further distinguish themselves in technological education and research.

It is recommended that the Royal College should consist of a Court, assisted by a Council and an Academic Board.

The Transformations $\alpha \rightarrow \gamma$ and $\gamma \rightarrow \alpha$ in Iron-Rich Binary Iron–Nickel Alloys

By N. P. Allen, D.Sc., M.Met. and C. C. Earley, B.Sc.

SYNOPSIS

The work described in this paper has been carried out to determine the effect of nickel on the rate and mode of the transformation in iron–nickel alloys. It forms part of a wider study of the effect of nickel on the transformations in iron.

On cooling iron–nickel alloys, the γ-solid solution transforms to a supersaturated α-solid solution α_2. During reheating this solid solution decomposes and the isothermal transformation has been followed dilatometrically and microscopically. The reaction has proved to be complex with two different types of phase change occurring. During isothermal transformation of alloys within the duplex $\alpha + \gamma$ field, the supersaturated solid solution α_2 decomposes into two other solid solutions of different nickel contents whereas, at similar temperatures, alloys initially in the γ-phase show no evidence of transforming isothermally $\gamma \rightarrow \alpha$. The kinetics of the slow isothermal transformation $\alpha \rightarrow \gamma$ are briefly discussed.

IRON and nickel form two solid solutions, α and γ, whose structures are body-centred and face-centred cubic respectively. Over a wide range of compositions and temperatures alloys in true equilibrium consist of a mixture of the two solid solutions. The generally accepted iron-rich portion of the equilibrium diagram below 1000° C. is that given by Owen and Liu[1] and is shown in Fig. 1. Also plotted on the same figure are the temperature ranges over which the $\alpha \rightarrow \gamma$ transformation takes place on continuous heating and $\gamma \rightarrow \alpha$ on continuous cooling, obtained by Jones and Pumphrey.[2] These latter results when plotted form a heating and cooling phase diagram which is referred to as the 'metastable' diagram in this paper to distinguish it from the true equilibrium diagram. The α-phase formed on continuous cooling is a supersaturated solution containing the same proportion of nickel as the γ-phase from which it is formed. It is generally referred to as the α_2-phase.

Alloys initially in the γ-state when cooled to, and held at, temperatures within the duplex $\alpha + \gamma$ field show no evidence of transforming isothermally, whereas alloys initially in the α_2-state will transform at constant temperature on heating to a temperature not too far removed from the temperature of the spontaneous phase change $\alpha \rightarrow \gamma$ on continuous heating. During the isothermal transformation $\alpha \rightarrow \gamma$, the supersaturated solid solution α_2 decomposes into two other solid solutions of different nickel contents.

DILATOMETRIC WORK

Initially a series of pure binary iron–nickel alloys containing 9–18 atomic-% of nickel* was prepared and the progress of the $\alpha_2 \rightarrow \alpha + \gamma$ transformation was recorded by a dilatometric method at a series of temperatures from 580° C. to 620° C. at 10° C. intervals. At these temperatures it was thought that the volume changes were sufficiently large for an accurate measurement of the transformation rates to be made. All the alloys were completely in the α_2, *i.e.*, supersaturated α, condition, initially at room temperature. This was confirmed by X-ray work which has shown the complete absence of the γ-phase in the specimens examined.

Preparation of Alloys

The alloys were made from Swedish iron and Mond nickel powder, both of very high purity. The Swedish iron was melted in air in magnesia crucibles, which further reduced the already low carbon, silicon, and sulphur contents. The oxidized Swedish iron was then remelted with the briquetted nickel powder in crucibles of pure sintered alumina using a high-frequency induction furnace. Hydrogen at atmospheric pressure was passed over the molten alloys for 4 hr. During solidification hydrogen was passed through the furnace at the same rate but the system was pumped down to a pressure of about 1 mm. of mercury. Subsequent microscopic examination showed that the hydrogen treatment had effectively deoxidized the alloy.

The weight of the ingots was about 200 gm. and they were forged down at 1100–1150° C. from $1\frac{1}{4}$-in. dia. cylinders to bars of section 0·6 in. × 0·3 in. approx. The bars were homogenized at 1300° C. for 24 hr. in a vacuum of 0·01 mm. of mercury. Microscopic examination indicated that the coring present in the original ingots had been removed, and analyses from different portions of the bars were almost identical, indicating that little, if any, segregation was present. The samples for chemical analysis and for dilatometric and X-ray examination were taken from the homogenized bars; all X-ray experiments were carried out using lump specimens. The nickel contents of the alloys were 9·5, 13·3, 13·7, 14·6, 15·3, 16·2, and 18·0 at.-%.

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Dr. Allen is Superintendent of the Metallurgy Division of the National Physical Laboratory, and Mr. Earley is a research worker in the same Division.

* Throughout this paper compositions are given in at.-%, unless stated otherwise.

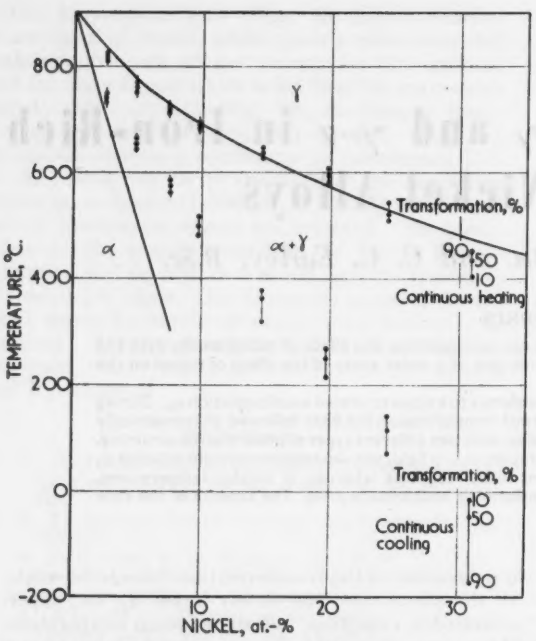


Fig. 1—Iron–nickel equilibrium diagram (Owen and Liu[1]) and transformation temperatures on continuous heating and cooling. Curves show phase boundaries of equilibrium diagram

Impurities present were not determined analytically, but the weight-% of other elements in alloys prepared in a similar manner from the same materials, but on a larger scale, were of the following order :

C	0·005	S	0·005
Mn	0·005	P	0·001
Si	0·002	O_2	0·002
Cr	0·001	N_2	0·001
Cu	0·005	H_2	trace
Al	0·001		

To eliminate errors caused by heterogeneity which might be produced in the alloys by certain heat-treatments, new specimens were used for each experiment. Alloys from a previous investigation[2] were used for the microscopic study of alloys containing less than 9% and more than 18% of nickel.

Experimental Procedure

The type of dilatometer used was similar in design to that described by Allen, Pfeil, and Griffiths,[3] the specimens being 1·14 in. long and 0·11 in. in dia. with conical ends with a semi-vertical angle of 60°. A rectangular lead bath 8 in. × 2 in. and 4 in. deep was constructed to take three separate dilatometers side by side. Thus three specimens could be inserted simultaneously into a single lead bath and the changes in length of each specimen could be read on three separate dial gauges. A cine camera and timing unit enabled readings of the dial gauges to be photographed either continuously or intermittently. With the slow

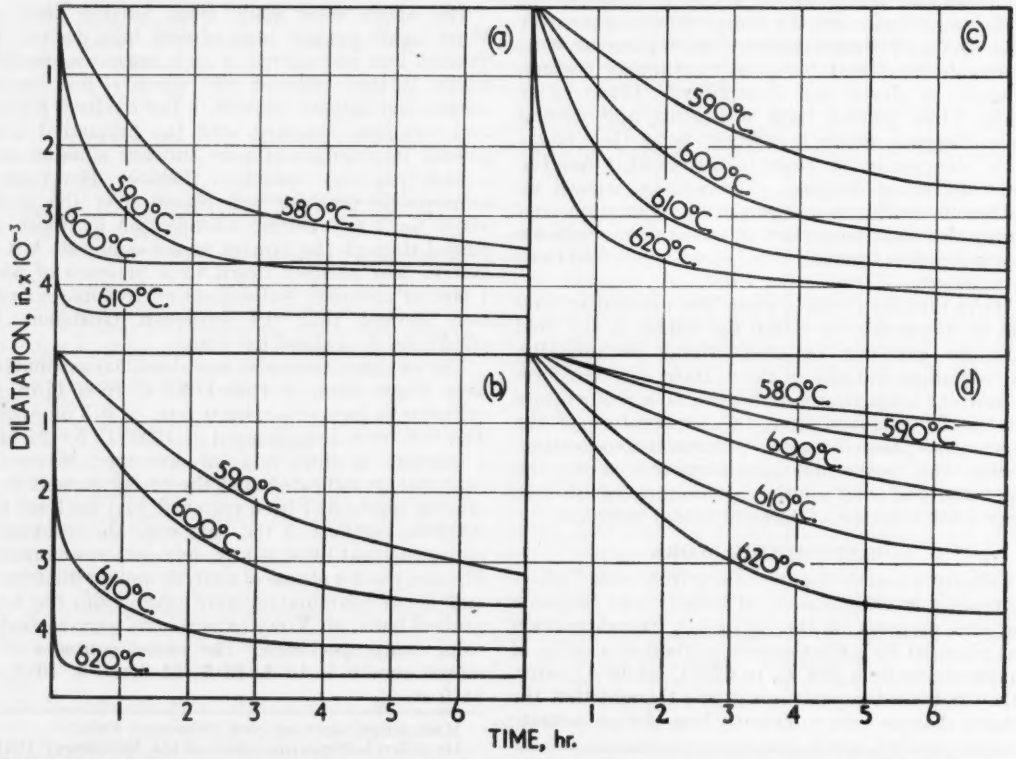


Fig. 2—Dilatation/time curves for various nickel alloys at different temperatures: (*a*) 18·0% Ni, (*b*) 16·2% Ni, (*c*) 15·3% Ni, (*d*) 13·7% Ni

reactions observed the dial gauge readings were conveniently recorded automatically at 5 or 60 min. intervals; with continuous running the camera enabled records of the fastest transformations to be satisfactorily made.

Three alloys of the series were held simultaneously at constant temperature usually for a period of 7 hr. During the insertion of the specimens and subsequently, the temperature was maintained steady within $\pm$ 2° C. The specimens took approx. 100 sec. to reach the temperature of the bath. For each alloy, contraction/time curves were drawn, the contraction observed being proportional to the amount of the γ-phase formed.

Results

Dilatation or contraction/time curves for the 18·0%, 16·2%, 15·3%, and 13·7% nickel alloys are shown in Fig. 2. These curves can be divided into two classes:

(*a*) Those showing a rapid initial contraction, *i.e.*, a rapid phase change, without an induction period, followed by slow transformation

(*b*) Those showing a slow contraction, *i.e.*, a slow phase change, with an induction period.

Examples of (*b*) are those for the 16·2%, 15·3%, and 13·7% nickel alloys transformed at 600° C., the induction period with the 13·7% nickel alloy being of the order of 15 min. as shown in Fig. 2*d*. Examples of (*a*) are the 18·0% nickel alloy transformed at 600° C. and 610° C. and the 16·2% nickel alloy transformed at 610° C. and 620° C. as shown in Figs. 2*a* and *b*.

Gradients were measured at appropriate points along the contraction/time curves and this enabled the rates of transformation to be calculated. The rates of transformation plotted against the percentage of the alloy transformed to equilibrium are shown in Figs. 3*a–d* for the various alloys; Fig. 3*e* gives the rates of transformation of three alloys at 600° C.

Rapid Type of Phase Change—Calculations for the initial speed of the rapid phase change gave a transformation rate in excess of 2000% per hr. and this is considered to be low in view of the impossibility of heating the whole mass of the specimen to the required temperature in the short periods during which the reaction proceeded. This type of phase change is thus very fast and the transformations may be considered as almost instantaneous. In a few experiments the maximum dial readings, as calculated by the coefficient of expansion, were not obtained since, in the few seconds when the alloy was expanding over the last 10° C. up to 620° C. for example, transformation and hence contraction were already proceeding before the final temperature had been attained. These two effects together gave a low maximum reading and in turn an abnormally low reading for the total dilatation change during the transformation.

The proportion of the alloy transformed instantaneously depends on the final temperature and there is a striking similarity to the martensite type of

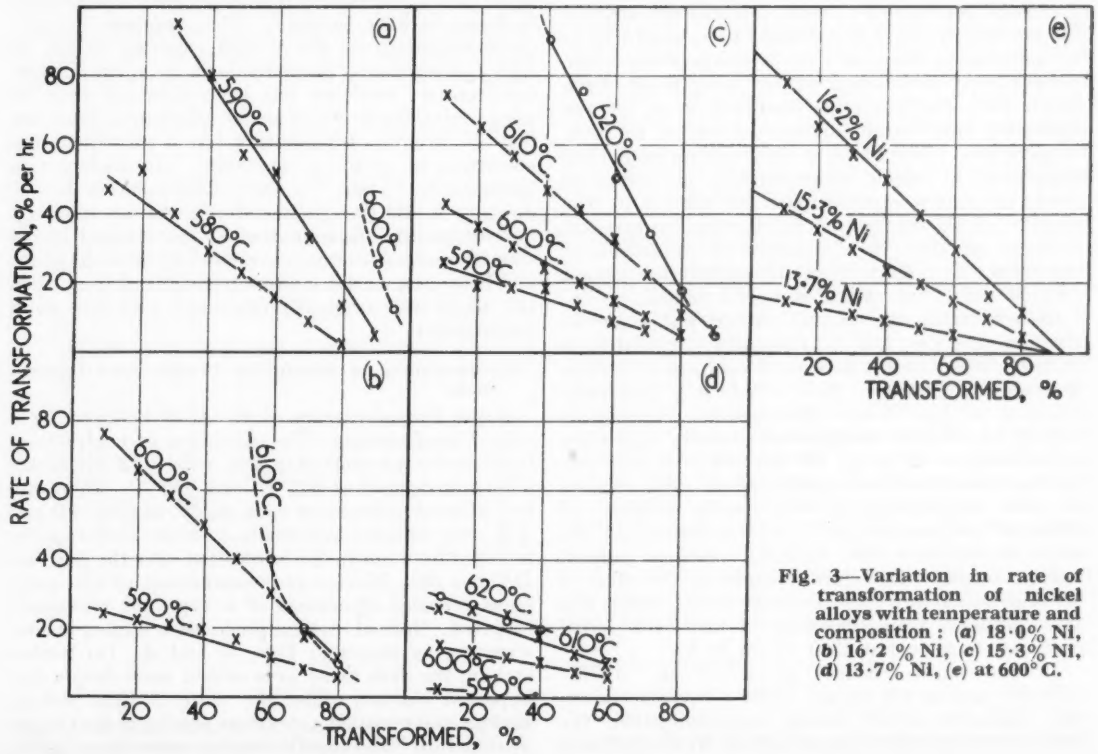


Fig. 3—Variation in rate of transformation of nickel alloys with temperature and composition: (*a*) 18·0% Ni, (*b*) 16·2 % Ni, (*c*) 15·3% Ni, (*d*) 13·7% Ni, (*e*) at 600° C.

transformation produced on cooling. On continuous heating at each successively higher temperature, further transformation of the alloy occurs and this results in the characteristic dilatation/temperature curve. On the other hand the contraction/time curves show that if the temperature is maintained constant the instantaneous transformation is followed by the slow type of transformation.

The present work has also shown that the rapid phase changes on heating and cooling cannot be suppressed by either very rapid heating or rapid cooling. A 16·2% nickel alloy heated and cooled 20 times through the transformation temperature had preserved its α_2-structure, no γ-phase being detected in the X-ray spectrogram. The transformations on continuous heating and cooling thus apparently bear little direct relation to the equilibrium diagram and are to be considered simply as γ breaking down into the supersaturated α, *i.e.*, α_2, the reverse transformation $\alpha_2 \rightarrow \gamma$ occurring on heating.

Slow Type of Phase Change—The slow type of phase change is considered to be one in which extensive diffusion occurs, the single supersaturated α_2-solid solution splitting up into the two equilibrium α- and γ-solid solutions, respectively poorer and richer in nickel.

The speed of the slow type of transformation varies greatly both with nickel content and temperature. The breakdown of the homogeneous supersaturated solid solution α_2 occurs by the progressive separation of the γ-phase of the equilibrium nickel content while the matrix approaches the equilibrium α condition.

At the end of the dilatometric experiments the specimens were cooled to room temperature and the γ-phase rich in nickel transformed to α_2 according to the metastable diagram over a temperature range corresponding to its composition. X-ray results have shown the complete transformation to α_2 of the separating equilibrium γ-phase on cooling to room temperature. Thus, whilst at the end of an isothermal experiment in which transformation has occurred slowly and has completed itself, the alloy is in true equilibrium, the resulting cooling to room temperature produces an alloy in a condition of metastability, consisting of a mixture of an equilibrium α-solid solution and a supersaturated α-solid solution.

In isothermal experiments carried out at lower temperatures, *e.g.*, 450° C., the γ-phase separating is so rich in nickel that it does not decompose on cooling to room temperature. Such retained γ is readily detected in the X-ray spectrogram. Subsequent cooling to sub-zero temperatures results in further transformation of $\gamma \rightarrow \alpha_2$. At the end of a slow isothermal transformation experiment the alloy consists at room temperature of two α-solid solutions of different composition and if re-transformed at the same temperature the reaction proceeds almost instantaneously. To remove completely the effect of the segregation into two compositions as a result of a slow diffusion transformation, it has been found necessary to anneal at 1300° C. for 24 hr.

In the phase changes $\alpha_2 \rightarrow \alpha + \gamma$ an 'uphill' diffusion mechanism occurs whilst a reverse 'downhill' diffusion occurs during homogenization, the latter being controlled almost entirely by the diffusion of nickel in γ-iron, the rate of which is comparatively low.

MICROSTRUCTURES IN IRON-NICKEL ALLOYS

The results of the dilatometric studies were used to carry out appropriate heat-treatment of specimens for microscopic examination to confirm that two types of phase change suggested by dilatometric work were real, and to provide further information on the nature of such phase changes.

Much previous microscopic work has been carried out by other workers but the results have been difficult to interpret. The present work includes a systematic study using specimens transformed in the lead bath under conditions identical to those which the dilatometric specimens underwent during the slower transformations. With the very fast transformations, complete dilatometric experiments have been carried out followed by microscopic examination of the actual specimens.

Microstructures Produced by Continuous Heating and Cooling

Alloys containing 9–18% of nickel were microscopically examined after continuous heating and cooling. Dilute solutions of nitric acid in alcohol were used to etch the specimens. The specimens were not readily etched in this solution, which is in keeping with the fact that the alloys were a homogeneous single phase. On prolonged etching a structure, apparently duplex in character, was observed, and this is characteristic of the α_2-phase present in all the specimens. This α_2-structure, as it is most conveniently termed, in an 18·0% nickel alloy repeatedly heated and cooled is shown in Figs. 5*a* and *b*. This structure is apparently indicative of the γ-solid solution, stable at high temperatures, breaking down to α_2 on cooling. Confirmatory evidence has been obtained with an alloy containing 30·9% of nickel, which on cooling from 900° C. to room temperature has a microstructure consisting of grains of austenite. On cooling this specimen to −180° C., the γ-solid solution breaks down to α_2 and the specimen has a characteristic α_2-microstructure. Examination of the original ingots showed a microstructure characteristic of the α_2-phase and hence the γ-solid solution transformed to α_2 when the alloys were originally made and cooled to room temperature.

Microstructures of Specimens Transformed Isothermally

Rapid Transformation of the Alloy Followed by a Slow Transformation—The dilatation or contraction/time curves are plotted in Fig. 4 for a 13·3% nickel alloy transformed at 643° C. and 650° C. There are two distinct portions of each curve, namely *AD* and *AB*, over which transformation occurs very rapidly, followed by a much slower reaction over the portions *DE* and *BC*. Microscopic examination of the specimens revealed structures of a type not previously reported. Normal etching produced a duplex macrostructure as shown in Figs. 5*c* and *d*. On further etching the dark areas were etched more deeply and appeared blacker, whilst the white or light etching background revealed a structure similar to that of the α_2-structure. The rapidly etching areas when lightly

etched and examined at a high magnification appeared to be duplex, but as the areas were few and small the resolution of the duplex structure was difficult. The two distinct types of areas in a heavily etched specimen are shown in Fig. 6*a*. The light etching area has the typical α_2 structure; the dark etching area is shown resolved in Fig. 6*b*; the microstructure of this area is duplex. For clarity the type of structure shown in Figs. 5*c* and *d* will be called a macroscopically duplex type of structure, whilst the term microscopically duplex structure will refer to the type of microstructure shown in Fig. 6*b*. This macroscopically duplex type of structure is observed whenever transformation of the α_2 occurs in two stages as, for example, in an 18·0% nickel alloy at 600° C. (*see* Figs. 6*c* and *d*). To reveal the α_2 type of structure in the background, a long etching period is necessary which etches very deeply the areas which are duplex on a microscopic scale. Figure 7*a* shows the structure produced in a 24·4% nickel alloy transformed isothermally at 520° C. Similar structures have been observed in alloys of lower nickel content accurately heat-treated at the appropriate temperatures for a sufficient time. With the lower nickel alloys the α_2 type of structure in the light etching areas becomes less marked and for alloys containing 5% of nickel and less, an ordinary grained structure similar to ferrite is observed (*see* Fig. 7*b*).

In contrast, in the high nickel alloys transformed at low temperatures the isothermal product of the reaction has a marked acicular appearance. Figure 13*d* shows a 30·9% nickel alloy heated for 20 hr. at 435° C. after it had been cooled to — 180° C. Initial cooling to — 180° C. transformed the alloy to α_2 and the transformation during 20 hr. at 435° C. proceeded in two stages, an initial very rapid reaction followed by a slower reaction. The microstructure throughout

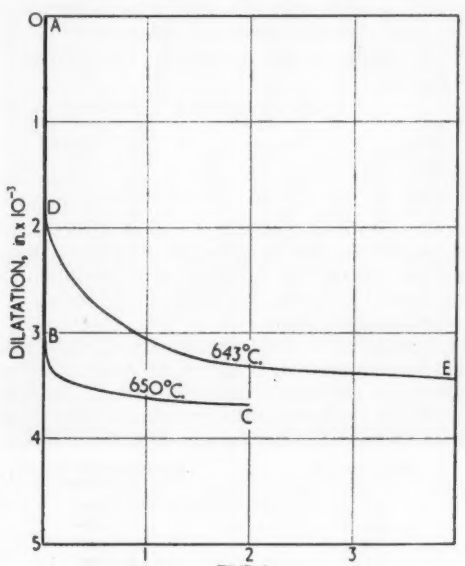


Fig. 4—Dilatation/time curves for a 13·3% Ni alloy transformed at 643° C. and 650° C.

was acicular, but large areas etched very readily in comparison with the remainder of the specimen; these areas are considered to be those where extensive diffusion had occurred.

Slow Transformation Throughout the Alloy—Where slow transformation occurs throughout the specimen, *e.g.*, in a 15·3% nickel alloy at 600° C., the microstructures are uniform if the transformation has proceeded to completion and are readily etched showing a duplex microstructure. To resolve many of these structures examination at high magnifications was necessary in addition to repeated polishing and etching to delineate the structures clearly.

Characteristics of the Duplex Microstructure

The characteristics of the duplex microstructure and its rate of formation vary according to the nickel content and the temperature. With increasing nickel content the structure becomes finer and more acicular. The general change in type of structure is shown in Figs. 8 and 9. The 7·4% and 9·7% nickel alloys have been included in Figs. 8 and 9 for comparison purposes. In each case the specimens, with the exception of the 19·7% nickel alloy (Fig. 9*d*), have been heat-treated, at temperatures lying within the $\alpha + \gamma$ field of the equilibrium diagram, for times sufficient to allow the transformation to be completed and equilibrium to be attained. The 19·7% nickel alloy has been transformed at 450° C. for 1000 hr. and the reaction is still far from being completed. Since the low nickel alloys exhibit a coarser structure at the end of the transformation it is easier to study microscopically the progress of the reaction in these alloys and this has been carried out using a 4·9% nickel alloy. It has, however, the disadvantage that the typical α_2-microstructure is not very evident in those areas which were γ at the transformation temperature. The two phases present in these microstructures consist of α of the equilibrium composition and α_2 resulting from the spontaneous decomposition of γ of the equilibrium composition as the alloys were cooled to room temperature.

Microscopical Study of a 4·9% Nickel Alloy

Specimens of a 4·9% nickel alloy were heat-treated at 740° C. for ½, 1, 2, and 100 hr. respectively. The resulting microstructures (*see* Fig. 10) show that the slow transformation is a reaction involving nucleation and growth. Originally nucleation appears to occur predominantly at grain boundaries and then proceeds within the grains, possibly along crystal planes. Nucleation appears to occur mainly during the initial part of the reaction and the growth of the nuclei occurs very slowly over the latter stages of the transformation. A similar process of nucleation and growth occurs with other alloys and the microstructures produced in a 15·3% nickel alloy are shown (at a higher magnification) in Fig. 11. With the higher nickel content the structure is much finer, but the nucleation and growth are still apparent.

Effect of Increasing Temperature

Specimens of the 4·9% nickel alloy were heat-treated at 670° C., 740° C., 760° C., and 780° C. for times sufficient for the transformation to have

completed itself; the resulting microstructures are shown in Fig. 12.

At 670° C. the 4·9% nickel alloy transforms very slowly by splitting up into the two equilibrium compositions so that finally about 25% of the alloy consists of the γ-phase. This phase is shown up by etching because the wide difference in nickel content of the γ- and α-phases causes the interface of the two phases to be readily and clearly etched. A similar structure with increased areas of the γ-phase is shown in Fig. 12*b*, heat-treated at 740° C.

Figures 12*a* and *b* illustrate the increase in the number of nuclei with increasing temperature. At 760° C. the transformation proceeds in two stages, initially very rapidly and afterwards more slowly, whilst at 780° C. the complete $\alpha_2 \rightarrow \gamma$ reaction occurs rapidly; the typical α_2-structure is not apparent in these microstructures.

Effect of Nickel Content on Structures Produced at 670° C.

The dilatometric results have shown that to attain equilibrium at a given temperature, as the nickel content is lowered, the greater is the time required for complete transformation. The microstructures of the alloys of 4·9%, 7·4%, and 9·7% nickel, transformed to equilibrium at 670° C. in four weeks, 100 hr., and 16 hr., respectively, are shown in Figs. 13*a*, *b*, and *c*. There is a marked increase in the rate of nucleation with increase in nickel content.

Stability of the γ-phase

On cooling alloys, initally in the γ-state, to temperatures in the duplex $\alpha + \gamma$-phase field of the equilibrium diagram the γ-solid solution, in contrast to the supersaturated α-solid solution α_2, will not decompose. Previous dilatometric work has shown no evidence of isothermal transformation with several nickel alloys, even with a 2·5% nickel alloy at 800° C. for 46 hr.

Further work using the microscopic method after much longer periods of heat-treatment has confirmed the extreme stability of the γ-phase. Alloys containing 13·3% of nickel and 18·0% of nickel were heated to the γ-state and then cooled to 600° C. and 560° C. for periods up to and including 1000 hr. before finally being cooled to room temperature. No microscopic evidence of diffusion or separation of the α-phase was observed in either alloy. At corresponding temperatures alloys initially in the α_2-state would have transformed completely to equilibrium over a period of much less than 1000 hr. according to dilatometric results.

The only evidence of γ precipitating α at constant temperature has been obtained in a few alloys which had a complex heat-treatment. A specimen of an 18·0% nickel alloy transformed at 590° C. for 7 hr. showed a duplex macrostructure, indicating that transformation had occurred in two stages. The specimen was then reheat-treated at 590° C. for a further 93 hr. and the light etching areas, *i.e.*, the γ-phase, were unchanged except in very localized areas around regions where the duplex type of microstructure had previously occurred as a result of a slow diffusion transformation. Evidence of the α-phase separating under these conditions was found (*see* Figs. 7*c* and *d*). Similar evidence has been obtained of very localized precipitation of α in a 13·3% nickel alloy which had been given a similar type of heat-treatment.

KINETICS OF THE SLOW TRANSFORMATION

In the slow diffusion type of transformation nucleation and growth occur, and an analysis along the lines given by Johnson and Mehl[4] was attempted. In their first treatment N_v is the rate of general or random nucleation, G is the rate of radial growth of nuclei, assuming spherical growth of nuclei, and $f(t)$ the fraction transformed per unit time is given by

$$f(t) = 1 - e^{-\frac{\pi}{3} N_v G^3 t^4}$$

N_v and G are assumed constant during the reaction. An alternative treatment is based on the assumption that the nuclei are confined to the grain boundaries and are produced there at a uniform rate per unit of grain-boundary area. The equation is not necessary for present purposes and is too complex to be reproduced here.

The reactions in the iron–nickel alloys follow neither type of equation. They proceed too slowly in the later stages, and to account for this it is necessary to assume that either N_v or G decreases during the reaction. In Johnson and Mehl's analysis the rate of nucleation plays a small part compared with that played by the rate of growth. Examination of Figs. 12 and 13, however, suggests that in the iron–nickel alloys nucleation is very much more rapid in the faster reactions, and must influence the speed of the change appreciably.

In the iron–nickel alloys the rate of the diffusion type of transformation is roughly proportional to the amount of untransformed α_2. The ratio of the rate of the transformation to the amount of untransformed α_2 may therefore be used as a convenient measure of the velocity of the phase change. The transformation velocity of a 15·3% alloy measured in this way increases rapidly with increasing temperature, as follows:

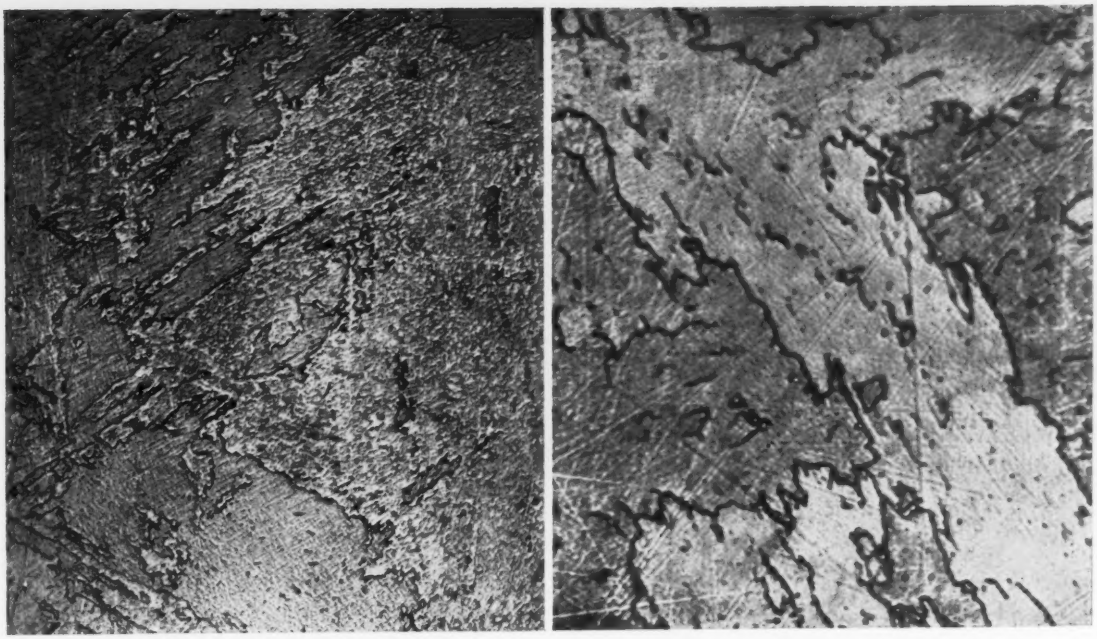
Temp., ° C.	Transformation Velocity, % per hr.	Activation Energy of Diffusion, cal./mol.
590	31·7	79,000
600	53	...
610	84	71,000
620	180	95,000

If it were assumed that the rate of transformation is governed by the rate of diffusion of nickel in iron the activation energy of diffusion deduced from these figures would be about 75,000 cal./mol., which is not an unreasonable value.

The variation of the transformation velocity with nickel content cannot, however, be accounted for by variations in the diffusion rate of nickel. At 600° C. the velocity rises very rapidly with increasing nickel content as the following figures show:

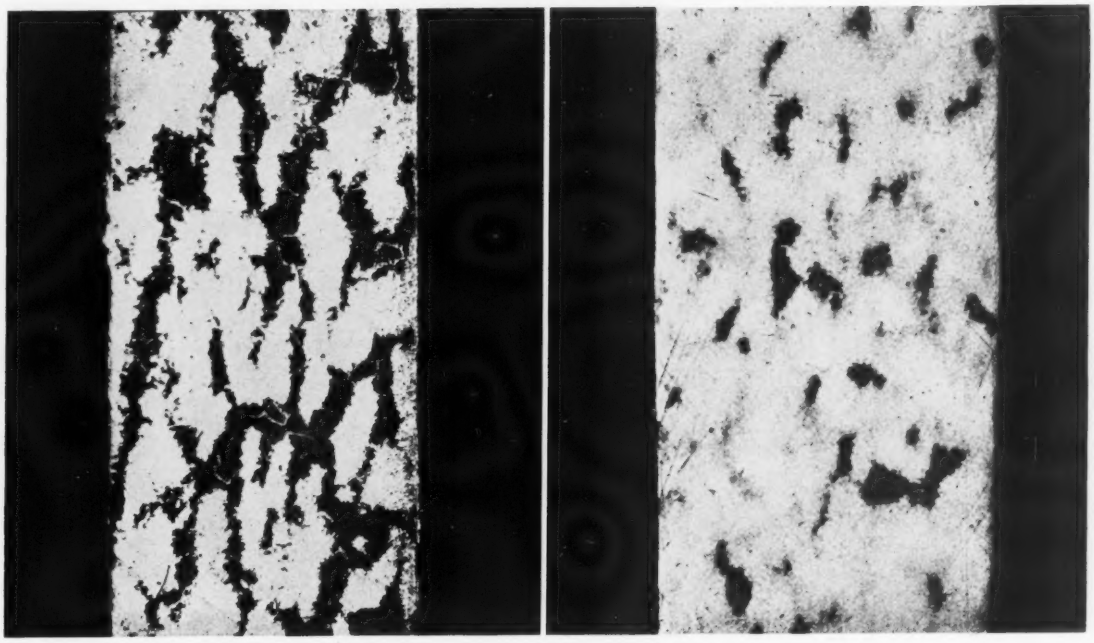
Nickel Content, at.-%	Transformation Velocity, % per hr.
13·7	19
15·3	53
16·2	95
18·0	about 230

Although the rate of diffusion of nickel in α-iron has not been measured, it is very unlikely that it would



(a) 18·0% alloy repeatedly heated and cooled showing α_2-structure × 150

(b) 18·0% alloy repeatedly heated and cooled showing α_2-structure × 1500



(c) 13·3% alloy transformed at 643° C. showing duplex macrostructure × 20

(d) 13·3% alloy transformed at 650° C. showing duplex macrostructure × 20

Fig 5—Structure of transformed nickel alloys

[*Allen and Earley*
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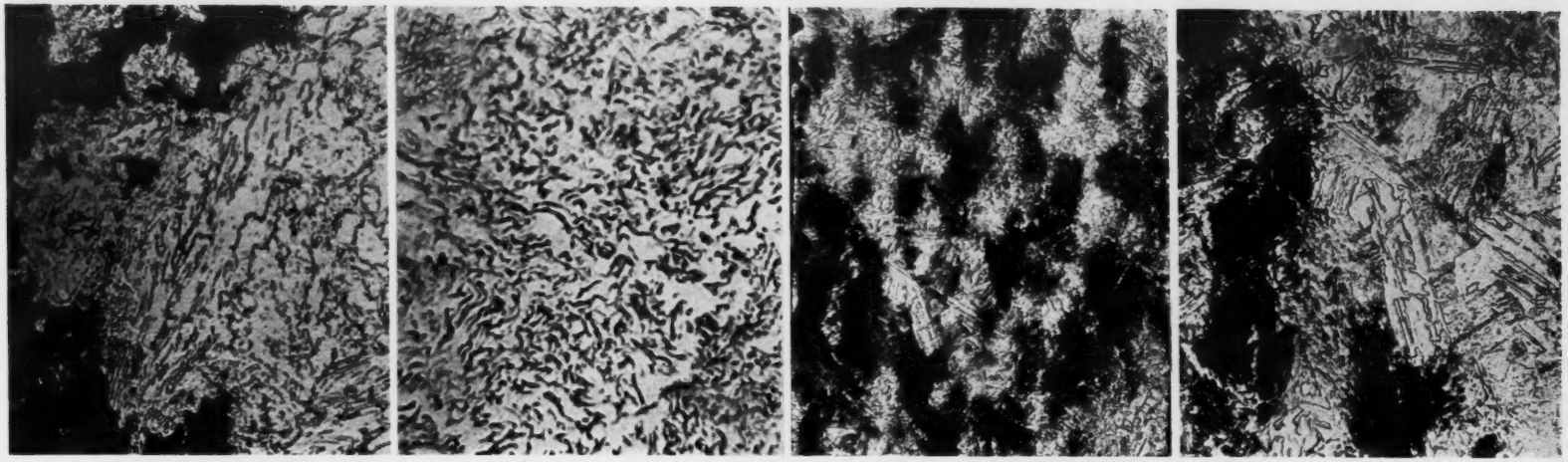


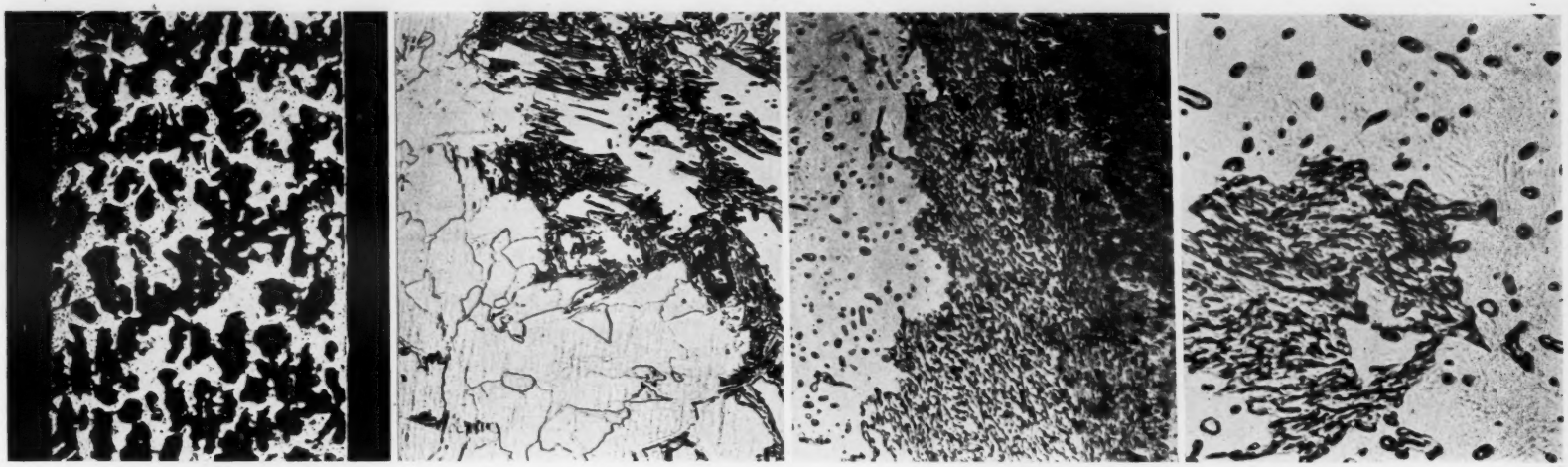
(a) 13·3% alloy transformed at 650° C. showing micro- and macrostructures × 500

(b) 13·3% alloy transformed at 643° C. showing duplex microstructure × 1500

(c) 18·0% alloy transformed at 600° C. showing duplex macrostructure × 20

(d) As (c) × 50

Fig. 6—Structure of nickel alloys transformed isothermally



(a) 24·4% alloy transformed at 520° C. showing α_2 structure after prolonged etching × 20

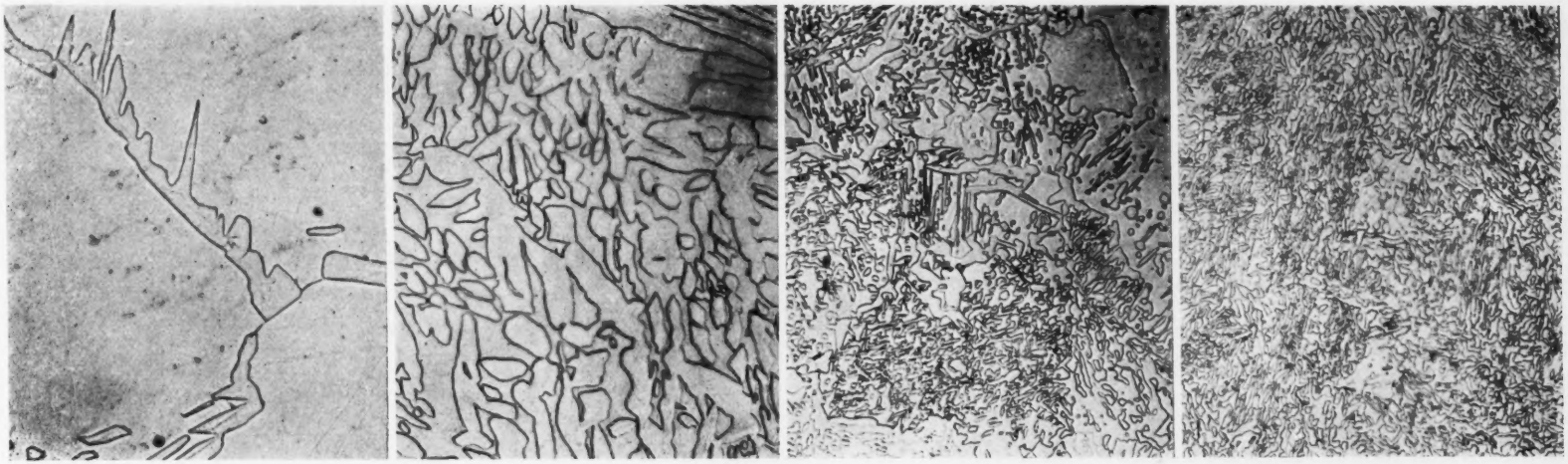
(b) 4·9% alloy transformed at 760° C. showing ordinary grain structure similar to ferrite × 150

(c) 18·0% alloy transformed at 590° C. for 100 hr. showing α-phase separating × 500

(d) As (c) × 1500

Fig. 7—Structure of nickel alloys transformed isothermally

Fig. 7—Structure of nickel alloys transformed isothermally



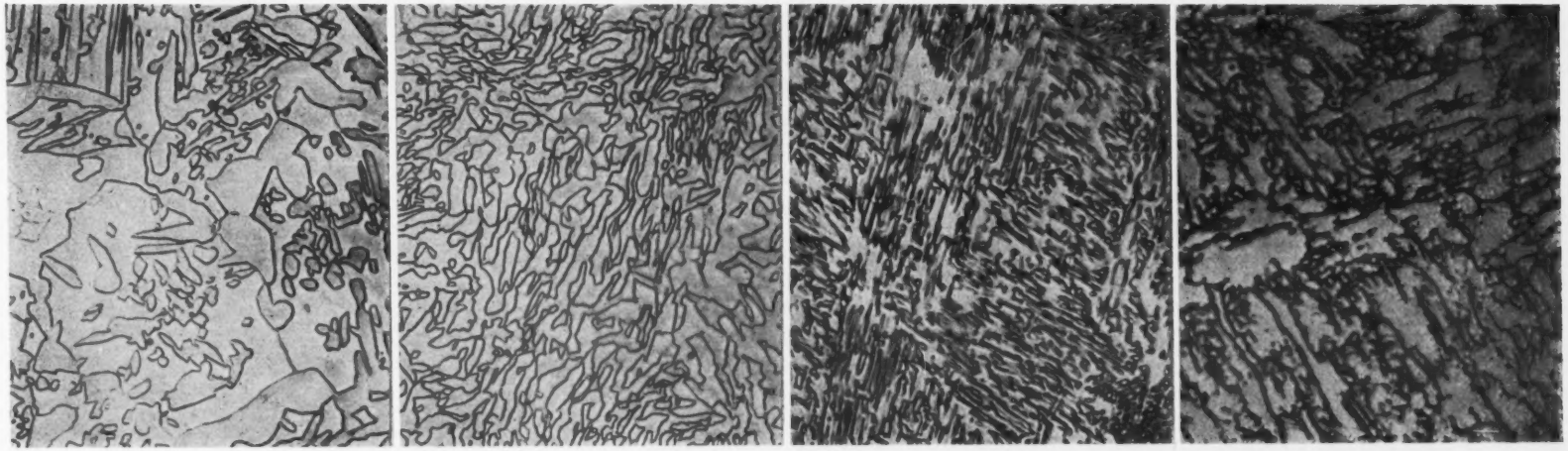
(a) 2·5% alloy transformed at 785° C.

(b) 4·9% alloy transformed at 740° C.

(c) 7·4% alloy transformed at 690° C.

(d) 9·7% alloy transformed at 650° C.

Fig. 8—Effect of nickel content and temperature on duplex structure × 500



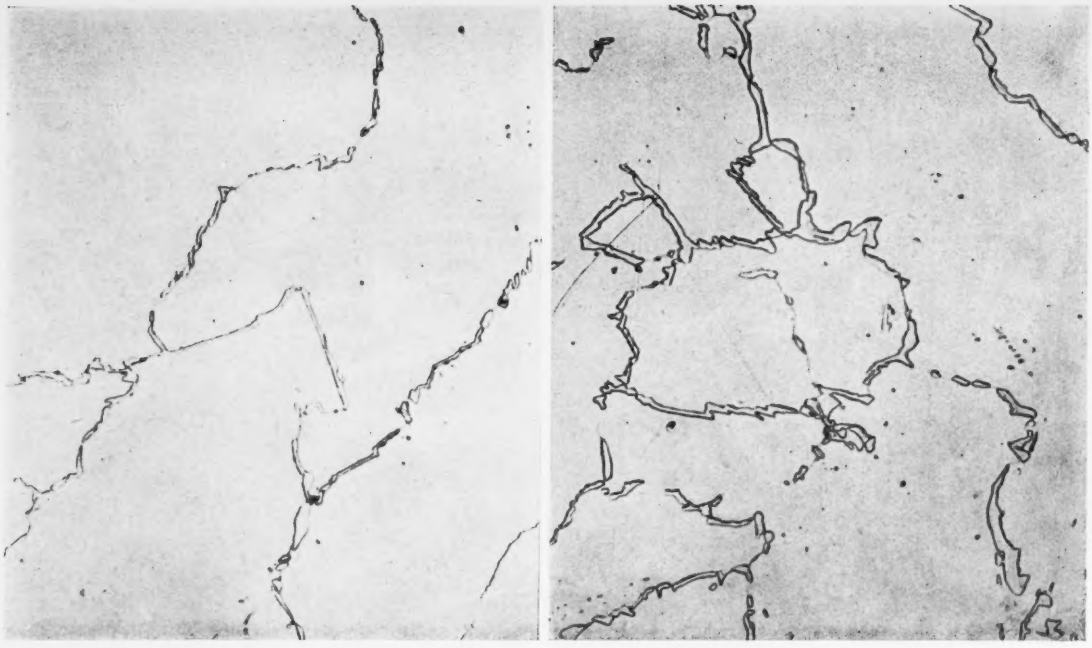
(a) 7·4% alloy transformed at 690° C.

(b) 9·7% alloy transformed at 650° C.

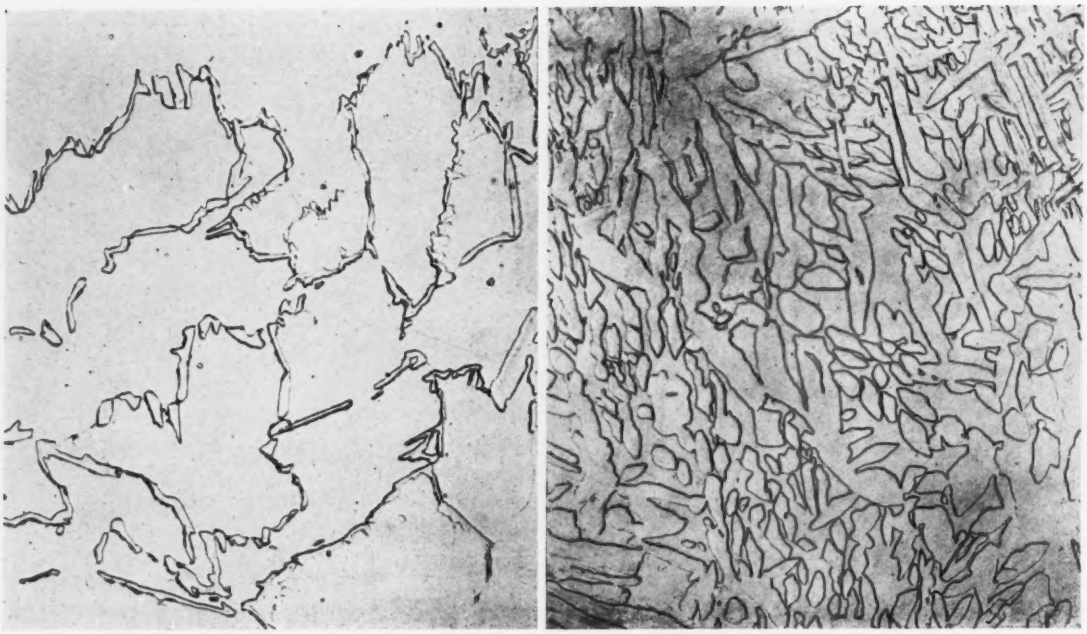
(c) 15·3% alloy transformed at 600° C.

(d) 19·7% alloy transformed at 450° C. for 1,000 hr. Reaction still incomplete

Fig. 9—Effect of nickel content and temperature on duplex structure × 1500

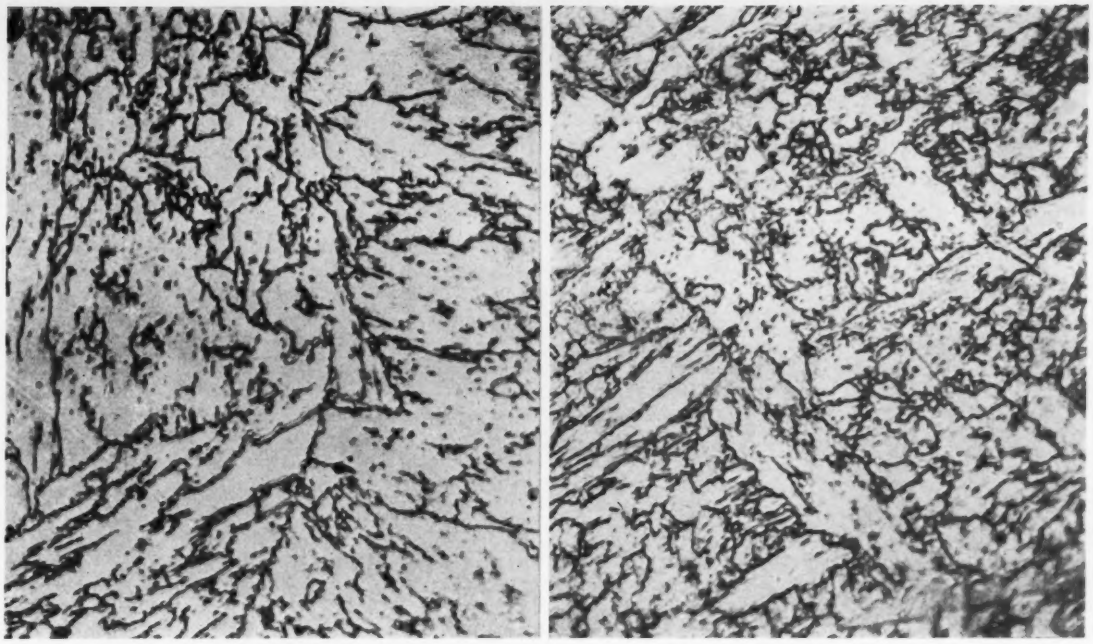


(a) ½ hr. (b) 1 hr.

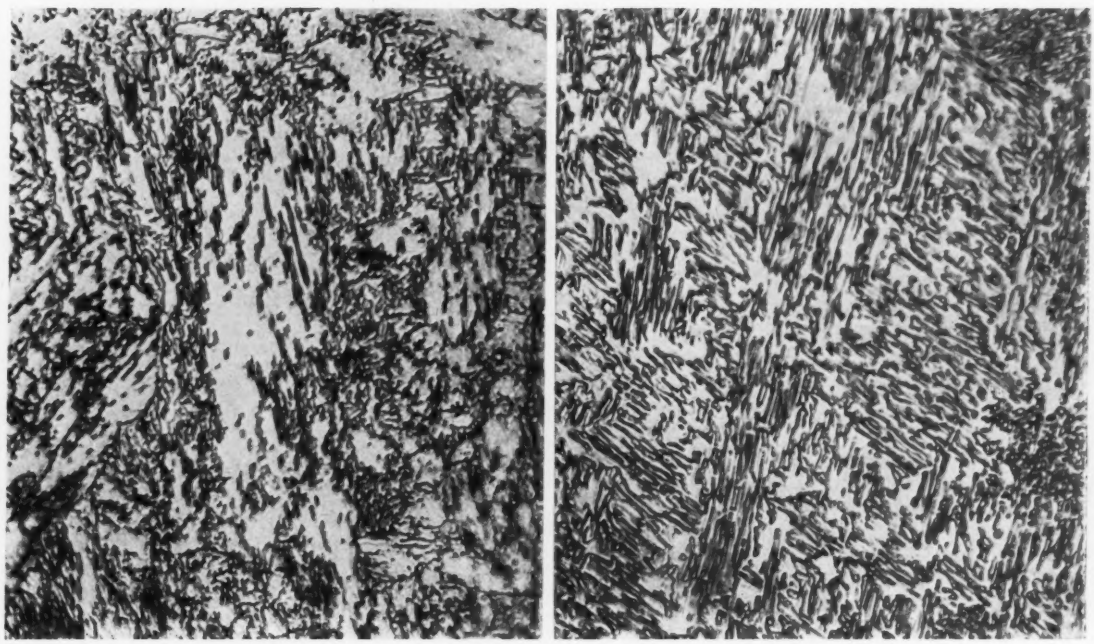


(c) 2 hr. (d) 100 hr.

Fig. 10—Structure of 4·9% nickel alloy transformed at 740° C. for varying times × 500



(a) $\frac{1}{3}$ hr. (b) $\frac{3}{4}$ hr.



(c) $1\frac{3}{4}$ hr. (d) 16 hr.

Fig. 11—Structure of 15·3% nickel alloy transformed at 600° C. for varying times × 1500

[*Allen and Earley*

(a) 670° C. for 4 weeks (b) 740° C. for 24 hr. (c) 760° C. for 2 hr. (d) 780° C. for 2 hr.

Fig. 12—Effect of increasing transformation temperature on structure of 4·9% nickel alloy × 500

(a) 4·9% alloy transformed at 670° C. for 4 weeks × 1500 (b) 7·4% alloy transformed at 670° C. for 100 hr. × 1500 (c) 9·7% alloy transformed at 670° C. for 16 hr. × 1500 (d) 30·9% alloy transformed at 435° C. for 20 hr. × 150

Fig. 13—Effect of nickel content on rate of nucleation

Fig. 13—Effect of nickel content on rate of nucleation

Table I

CALCULATION OF NUMBER OF ATOMS IN TRANSFORMATION NUCLEUS IN ALLOYS OF VARYING NICKEL CONTENTS AT CONSTANT TEMPERATURES

(Rate of transformation assumed to be proportional to rate of production of nuclei)

Temp., °C.	Nickel Content, at.-%	Transformation Velocity, % per hr.	Relative Transformation Rate	N (interaction neglected)	N (interaction included) $\Delta H = 2428$
590	18·0	147	4·9	281	286
,,	15·3	30	1	...	...
,,	13·7	3	0·1	358	336
600	18·0	230	4·3	400	402
,,	16·2	95	1·8	248	321
,,	15·3	53	1	...	...
,,	13·7	19	0·36	264	194
610	16·2	150	1·8	361	456
,,	15·3	83	1	...	...
,,	13·7	31	0·37	255	258

change with composition as rapidly as this, and some alternative explanation of the effect of nickel content must be found.

The reaction at 600° C. consists of the separation of γ crystals containing 18·5% of nickel from a matrix of α crystals having the composition of the alloy. It is interesting to consider the possibility that the difficulty of forming nuclei having the desired composition governs the rate of transformation. If the number of atoms in the nucleus is known it is possible to calculate the probability of a nucleus of one composition arising by chance in a matrix of another composition. In general, if the number of atoms in the group is N, and X and Y are the proportions of nickel in the matrix and in the nucleus respectively, then the probability that any given group of N atoms has the nickel content Y is given by

$$P = {}^{N}C_{YN}X^{NY}(1-X)^{(1-Y)N}$$

If it is assumed that the rate of transformation is proportional to this probability, the relative rates of transformation in two alloys of nickel contents x_1 and x_2 will be

$$\frac{R_{x_1}}{R_{x_2}} = \frac{{}^{N}C_{YN}x_1^{NY}(1-x_1)^{(1-Y)N}}{{}^{N}C_{YN}x_2^{NY}(1-x_2)^{(1-Y)N}} = \left\{\frac{x_1^{Y}(1-x_1)^{1-Y}}{x_2^{Y}(1-x_2)^{1-Y}}\right\}^{N},$$

where R_{x_1} and R_{x_2} are the rates of transformation in the alloy of nickel content x_1 and x_2, respectively.

By measuring R_{x_1} and R_{x_2}, and evaluating the expression within the brackets on the right-hand side of the equation, it is possible to calculate the value of N, the nucleus size.

The results of such calculations for alloys transformed at 590° C., 600° C., and 610° C., are given in Table I and it will be observed that at each temperature a value of N of about 300 is able to account for the relative transformation velocities observed.

In these calculations it is necessary to adopt for each transformation temperature a value for the

Table II

CALCULATION OF RELATIVE TRANSFORMATION RATES WITH TRANSFORMATION NUCLEI OF DIFFERENT SIZES IN VARIOUS ALLOYS AT DIFFERENT TEMPERATURES

Alloy	Temp., °C.	Transformation Velocity, % per hr.		Probability (calculated)	Calculated Relative Rate
		Observed	Relative		
15·3% Ni ($N = 40$)	590	31·7	1	0·122	1
	600	53	1·7	0·138	1·1
	610	84	2·6	0·153	1·25
	620	180	5·7	0·176	1·45
15·3% Ni ($N = 300$)	590	31·7	1	0·00849	1
	600	53	1·7	0·017	2
	610	84	2·6	0·0355	4·2
	620	180	5·7	0·054	6·4
15·3% Ni ($N = 1000$)	590	31·7	1	0·000052	1
	600	53	1·7	0·00076	14·6
	610	84	2·6	0·0054	104
	620	180	5·7	0·02	4000
18·0% Ni ($N = 300$)	580	70	1	0·0275	1
	590	147	2·1	0·0464	1·7
	600	230	3·3	0·0575	2·1
9·5% Ni ($N = 300$)	600	0	...	$6·5 \times 10^{-7}$	...

nickel content of the γ-phase which separates. This has been taken as the lowest nickel content of alloys which transform at that temperature without the formation of the dark etching duplex constituent that contains residual α. With rising temperature the nickel content of the separating γ-phase becomes progressively closer to the nickel content of the alloy. An increase in the transformation velocity with rising temperature would therefore be expected, and from this increase it is possible to obtain a second estimate of the value of N.

The procedure is illustrated in Table II. The last column shows the relative rates of transformation of the 15·3% nickel alloy calculated on the assumption that the nucleus contains 40, 300, and 1000 atoms. The observed relative rates of transformation (fourth column) agree well with a nucleus size of about 300 atoms, and it is clear that the assumption of a very much larger or much smaller nucleus size leads to calculated relative rates of transformation widely different from those observed. A nucleus of 300 atoms is in general agreement with the observed behaviour of an alloy with 18·0% of nickel. The velocity of the slow transformation throughout the range of nickel contents and temperatures covered by the experiments can thus be roughly accounted for on the assumption that the velocity is governed by the probability of the appearance of nuclei containing about 300 atoms. With a 9·5% nickel alloy at 600° C., assuming a nucleus size of 300, the calculated probability is $6{\cdot}5 \times 10^{-7}$, which is 10^{-5} times the probability of nuclei appearing in an 18·0% nickel alloy at 600° C. No transformation was observed when a 9·5% nickel alloy was held at 600° C. for 7 hr.; this is in agreement with the calculated probability. It should, however, be noted that the calculated probabilities given in the fifth column of Table II are such that very large numbers of nuclei would be present and would lead to the expectation that the reaction is very rapid, whereas it is, in fact, slow and proceeds from a much smaller number of nuclei.

In the above calculations it has been assumed that there are no mutual interactions between the iron and nickel atoms. If such interactions are to be taken into account it is necessary to consider the free-energy change associated with the formation of a nucleus. The free-energy change can be shown to be

$$N\,(f_1 - f_0)\left\{\left(\frac{df}{dc}\right)_{c_0}\frac{c_1 - c_0}{f_1 - f_0} - 1\right\}$$

where

- c_0 is the concentration of nickel atoms in the matrix
- c_1 is the concentration of nickel atoms in the nucleus
- f_0 is the free energy per atom of the matrix of composition c_0
- f_1 is the free energy per atom of the nucleus of composition c_1
- $\left(\frac{df}{dc}\right)_{c_0}$ is the slope of the free-energy/concentration curve at c_0

Denoting this by ΔF, the probability of the formation of a nucleus is proportional to

$$e^{-\frac{\Delta F}{kT}}$$

and if this is assumed to be proportional to the rate of transformation, and the free energy is known as a function of composition, N can be calculated. For the free energy of the α-phase, the values of Kubaschewski and von Goldbeck[5] have been used, thus:

Free energy per gram-atom of α-phase with concentration c of nickel

$$= 2420c - RT\left\{c\log_e c + (1-c)\log_e(1-c)\right\}\text{cal.}$$

and the values of N so obtained are given in Table I. There is a marked agreement with those obtained when interaction is neglected, probably because the heat of solution of nickel in α-iron is small, and is independent of the nickel content.

The hypothesis that the rate of transformation is largely influenced by these calculated probabilities is tenable, but more data should be made available and more information on the factors controlling the value of N, the nucleus size, is required before any conception of the reaction based upon these calculations can be adopted.

Acknowledgment

The work described above has been carried out as part of the research programme of the National Physical Laboratory and this paper is published by permission of the Director of the Laboratory.

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National Physical Laboratory

Details of the work of the National Physical Laboratory, which ranges from the testing of field glasses to the construction of the most advanced electronic calculating machine, are given in the Annual Report for the year 1949. The Report has been published for the D.S.I.R. by H.M.S.O., price 1*s.* 9*d.* It is divided into reports from each of the Divisions of the Laboratory.

The outstanding development in the Metallurgy Division is the regular production of iron of 99·96% purity. Ingots of pure iron and of alloys with manganese, silicon, nickel, and chromium containing up to 5% of the added element have been made. The ingots are each 25 lb., but the process could easily be operated on a larger scale. Testing of the material over a temperature range from 200° C. to −196° C. has begun. Pure iron will behave in a perfectly ductile manner at −14° C. and in a brittle manner at −16° C. In tensile tests, the pure iron is ductile at −73° C., but brittle at −186° C. The addition of up to 2% of manganese lowers the transition temperature in a notched bar impact test from −15° C. to about −50° C. but addition of 5% of manganese raises it to over 100° C.

Ionic Theory of Slag–Metal Equilibria

By P. Herasymenko, Dr.Nat.Sc., and G. E. Speight, B.Sc., F.R.I.C., F.I.M.

Part II—APPLICATIONS TO THE BASIC OPEN-HEARTH PROCESS

SYNOPSIS

The relationships between the total number of ions, N, or the ionic fraction of oxygen ions, O″, and the sum of acids, Σa (where $\Sigma a = SiO_2 + 0{\cdot}634P_2O_5 + 0{\cdot}90Al_2O_3$ expressed in percentage weights) can be represented by empirical curves. Using these relationships, the equilibrium ratios derived in Part I can be expressed as nomograms for the calculation of the oxygen content of liquid steel and of the desulphurization ratio from the slag analysis.

Oxygen content of the basic steel is a function of the content of FeO and of the sum of acids, Σa. It depends also on temperature and, especially, on the carbon content, because the activity coefficient of oxygen increases strongly with increasing carbon content. The analytically determined oxygen contents for a series of experiments made by the authors agree, within the limits of experimental errors, with the oxygen contents calculated from the slag analysis and corrected for the effect of temperature and of carbon. The desulphurization ratio (S)/[S] is a function of the content of FeO and of the sum of acids, Σa, and is not perceptibly influenced by temperature and carbon content.

The equilibrium between the trivalent and bivalent forms of iron in slag and liquid steel has been examined empirically. The ratio Fe_2O_3/FeO is found to be a function of the content of CaO and of the sum of acids, Σa, both for laboratory slags melted under equilibrium conditions and for basic open-hearth slags. Somewhat lower Fe_2O_3 contents and somewhat higher FeO contents in the open-hearth slags—as compared with laboratory slags of similar composition—are caused by analytical procedure (partial reduction of Fe_2O_3 by hydrogen and hydrogen sulphide when dissolving in hydrochloric acid). The slag in the open-hearth furnace can therefore be regarded as being practically in equilibrium with metal and very far from equilibrium with the furnace gases.

For the estimation of oxygen content and of the desulphurization ratio, the analytical content of FeO can be used without impairing substantially the accuracy of the results.

The equilibrium constant of the phosphorus reaction is more sensitive to variations in the activity of FeO and oxygen produced by small amounts of fluoride in basic slag; a displacement of equilibria is also possible by the formation of complexes between phosphate and fluoride ions. A comparison of the data shows that the dephosphorization ratio for the open-hearth process is higher than that for laboratory melts without fluoride ions in the slag. A further quantitative investigation of the effect of fluoride ions on the phosphorus equilibria is necessary, to establish the exact relationships which can be applied to practical steelmaking.

In Part I[1] equilibrium ratios for many of the important reactions in steelmaking have been derived, mainly from the laboratory work of Chipman and Quarrell and their associates.[2–5] In these ratios, slag concentrations are expressed as ionic fractions of the total ions present. The slag–metal relationships, therefore, are valid for the more usual weight concentrations only after laborious conversions of weight concentrations into ionic concentrations. In this paper the foregoing theoretical relationships are expressed in a manner more adapted to the practical problems of steelmaking, and where necessary are illustrated by presentation and discussion of actual steelmaking data.

CALCULATION OF IONIC CONCENTRATIONS AND RELATION TO NORMAL WEIGHT CONCENTRATIONS

The method of calculating the ionic concentrations in slag was outlined in Part I of this paper. Detailed study of many such calculations of laboratory and plant data reveals that the conversion of normal weight concentrations to ionic concentrations can be achieved with reasonable accuracy by empirical relationships, so that, except where great precision is required, the rather laborious calculations can be avoided. Thus, according to Figs. 1*a* and *b*, the total number of ions, N, and the ionic fraction of oxygen anions (O″) in slags can be derived from the weight percentage of the so-called 'acid' constituents, *i.e.*, SiO_2, P_2O_5, and Al_2O_3. Figures 1*a* and *b* show that both N and (O″) are functions of Σa only, where Σa represents the 'acidity' of the slag in terms of weight equivalents of SiO_2, and is equal to $SiO_2\% + 0{\cdot}634P_2O_5\% + 0{\cdot}90Al_2O_3\%$. This expression is derived from the fact that each mol of SiO_2 consumes two oxygen ions, and each mol of P_2O_5 and Al_2O_3 consumes three oxygen ions, in the formation of SiO_4'''', PO_4''', and AlO_3''', respectively. It follows that 1% of P_2O_5 is equivalent to 0·634% of SiO_2, and 1% of Al_2O_3 is equivalent to 0·90% of SiO_2. In approximate calculations (especially when the contents of P_2O_5 and Al_2O_3 are similar), the expression $\Sigma a = \%\ SiO_2 + 0{\cdot}75(\%\ P_2O_5 + \%\ Al_2O_3)$ may be used, 0·75 being a mean value for the two coefficients 0·634 and 0·90.

The values of N and (O″), for the range of Σa values found in basic open-hearth practice, are given in Table I. The precision of the empirical estimations of N and (O″) is slightly impaired at the 'acid' end of the series, *i.e.*, when Σa is greater than 30%. Analytical and incidental sampling errors may sometimes produce deviations, especially noticeable in (O″) when the calculated values are compared

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Dr. Herasymenko and Mr. Speight are in the Research and Development Department of the United Steel Companies, Ltd., Stocksbridge.

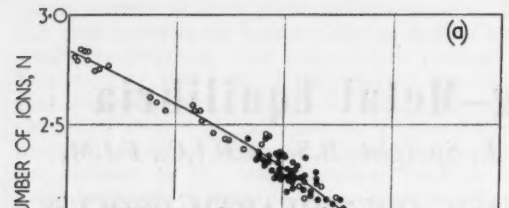

Fig. 1—Empirical relationship between the content of acids and (*a*) the total number of ions in 100 parts of slag, (*b*) the ionic fraction of oxygen ions

with those obtained from the mean curves (Figs. 1*a* and *b*), but in such cases the values of *N* and (O″) given by Figs. 1*a* and *b* are likely to correspond to the actual values more closely than those obtained by direct calculation.

It should also be pointed out that the relationships given in Figs. 1*a* and *b* are strictly applicable only to slags of low CaF_2 content. This seldom exceeds 3% in normal open-hearth practice, so that the effect of fluorspar on the empirical calculations for *N* and (O″) may be neglected.

THE EQUILIBRIUM CONTENT OF TRIVALENT IRON IN BASIC SLAGS

The slags investigated by Winkler and Chipman[2] and by Quarrell and co-workers[4] contained appreciable amounts of trivalent iron, which undoubtedly were such as would correspond to the equilibrium with the bivalent iron in slag and with the liquid iron. In both investigations the gas phase above the melts was non-oxidizing, as the slags were heated from above by an electric carbon arc.

Owing to the complex nature of the equilibria between trivalent and bivalent iron and oxygen ions in basic slags, and to the low accuracy of the data, derivation of the equilibrium laws in the form of equations has not been attempted. However, the dependence of the ratio Fe_2O_3/FeO on slag composition (*i.e.*, on CaO and Σ*a*) for the foregoing laboratory melts has been investigated empirically, with the results shown in Fig. 2. The ratio Fe_2O_3/FeO

Table I

TOTAL NUMBER OF IONS, *N*, AND THE O″ CONTENT OF BASIC SLAGS AT VARYING CONTENTS OF 'ACIDS,' Σ*a*

Σ*a*, %	*N*	(O″)
0	2·83	0·502
2	2·79	0·486
4	2·74	0·468
6	2·69	0·448
8	2·64	0·428
10	2·59	0·408
12	2·54	0·385
14	2·49	0·361
16	2·43	0·334
18	2·37	0·308
20	2·31	0·280
22	2·24	0·250
24	2·17	0·216
26	2·09	0·182
28	2·01	0·144
30	1·92	0·100
32	1·80	0·063

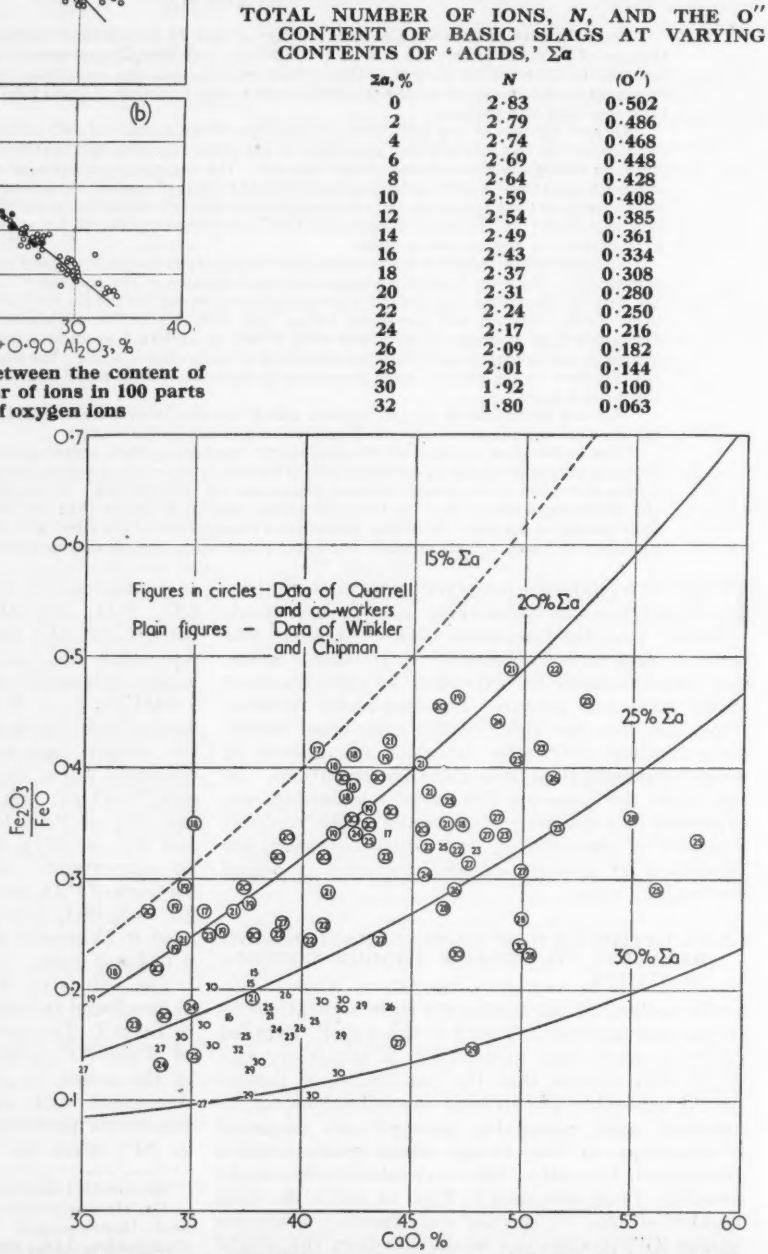

Fig. 2—Dependence of equilibrium ratio on the contents of acids and of CaO

increases with the content of CaO (or calcium ions) and decreases with the content of acids (*i.e.*, increases with the content of ' free ' oxygen ions). In spite of the comparatively wide scatter of the experimental data, the average equilibrium curves in Fig. 2 are reasonably certain, because of the large number of tests.

Figure 2 is important, because it provides a means of checking whether the content of Fe_2O_3 found on analysis of routine slag samples in basic open-hearth practice corresponds to its equilibrium value with bivalent iron and liquid iron. Thus a comparison of furnace data with Fig. 2 has shown that the analytically determined Fe_2O_3/FeO ratio in open-hearth slags closely corresponds to the equilibrium, provided that the tests are taken during the boil.

As the evaluation of the equilibrium ratios for the sulphur, oxygen, and phosphorus reactions involves the content of ferrous iron in the slag, it is important to know whether the analytically determined content of FeO represents its equilibrium value under the furnace conditions at the time of sampling. Figure 3 shows a comparison of FeO contents found on analysis with those for equilibrium conditions as calculated from the slag composition, *i.e.*, total Fe, Ca, and Σa (Fig. 2). The agreement is quite satisfactory, although the observed FeO contents tend to be somewhat higher than the equilibrium contents. This may arise during the analysis from the reduction of some Fe_2O_3 by hydrogen and hydrogen sulphide liberated when dissolving the open-hearth slag samples in hydrochloric acid. As the deviations are small, however, it can be concluded that, for practical purposes, basic open-hearth slags are in equilibrium with liquid metal. Another important conclusion is that the open-hearth furnace gases, which have a much higher partial pressure of oxygen than that of liquid metal, have little influence on the equilibria between slag and metal provided that the bath boils. It is possible that carbon monoxide liberated during the boil dilutes the furnace gases just above the slag surface to such an extent that an equilibrium between slag and bulk of the furnace gases cannot be approached.

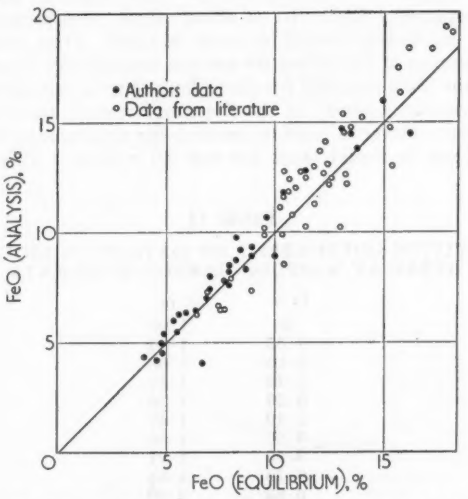

Fig. 3—Comparison of observed FeO contents in basic open-hearth slags, during the boil, and the equilibrium FeO contents derived from slag analysis by means of Fig. 2

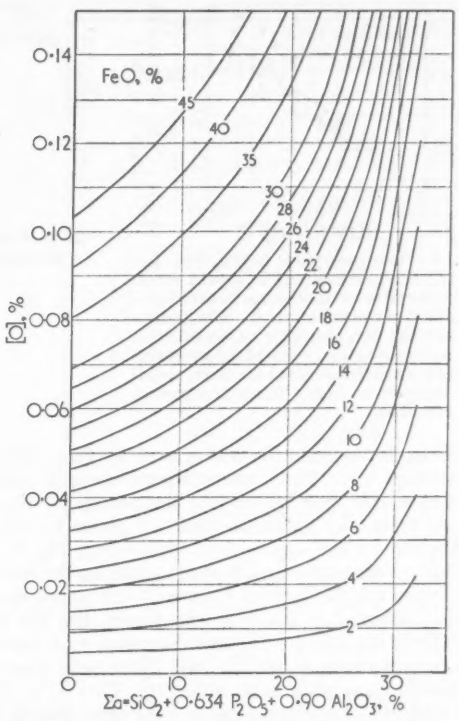

Fig. 4.—Nomogram for estimation of the oxygen content of liquid basic steel from the analysis of basic slag at 1600° C.

ESTIMATION OF OXYGEN CONTENT OF LIQUID STEEL FROM THE ANALYSIS OF BASIC SLAG

In Part I of this investigation it was shown that the oxygen content of liquid carbon-less steel is given by the expression :

$$[O] = \frac{(Fe{+}{+})}{A(O'')^{\frac{1}{2}}}$$

where A is a constant depending on temperature only. Using the empirical relationships given in Figs. 1*a* and *b*, the oxygen content of carbon-less liquid steel has been calculated as a function of the weight percentage of the acid constituents of slag (Σa = $SiO_2\%$ + $0{\cdot}634P_2O_5\%$ + $0{\cdot}90Al_2O_3\%$) for various contents of FeO in the slag at 1600° C. The results are shown in the nomogram, Fig. 4.

When applying this nomogram to practical examples, two corrections are necessary. Since the constant A depends on temperature, correction coefficients are required for tests taken at other temperatures. Coefficients derived from the variation of the constant A are given in Fig. 5; they are numerically equal to the relative solubility of oxygen in steel at a given temperature in contact with an FeO slag, when the solubility at 1600° C. is put equal to unity. (The solubility of oxygen in liquid steel

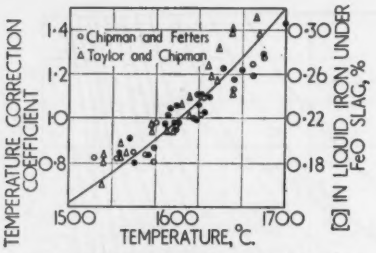

Fig. 5—Temperature correction for the oxygen content in liquid steel, derived from the temperature variation of the constant *A*. Black dots are oxygen contents of liquid iron in equilibrium with slags containing mainly iron oxides with small amount of MgO (from magnesite crucible)

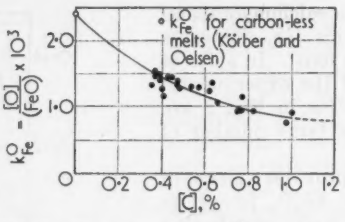

Fig. 6—Dependence of k^O_{Fe} on [C] for acid open-hearth tests

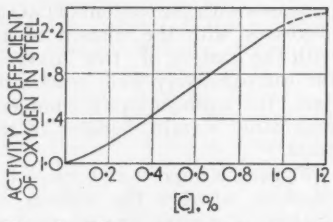

Fig. 7—Effect of carbon on the activity coefficient of oxygen in steel

has been determined for this system by Chipman and co-workers.[6–8]) Thus, values for the oxygen content of carbon-less iron at specific temperatures are obtained from the value at 1600° C. given by Fig. 4, multiplied by the appropriate factor from Fig. 5.

The correction for the effect of carbon on the content of oxygen can be derived from a recent paper by one of the authors,[9] in which it was shown that the ratio [O]/(FeO) for liquid acid steel decreases with increasing carbon content (*see* Fig. 6). Since acid slags are in equilibrium with solid silica (*cf.* Part I, p. 177), the activity of oxygen ions in acid open-hearth slag can be regarded as constant and the analytical FeO content as proportional to (Fe^{++}). Therefore, the variation of the [O]/(FeO) ratio with increasing carbon content is caused by an increase in the activity coefficient of oxygen dissolved in steel. By equating the activity coefficient of oxygen in carbon-less steel to unity, the oxygen activity coefficients (f_O) for various carbon contents were calculated (*see* Table II and Fig. 7). Thus, dividing the oxygen content (Figs. 4 and 5) by the activity coefficient for the respective carbon content gives the actual oxygen content.

It should be pointed out that Marshall and Chipman[10] have come to an opposite conclusion as to the effect of carbon on the activity coefficient of oxygen dissolved in liquid steel; *viz.*, that carbon decreases the activity coefficient f_O. Serious doubts can be expressed as to the correctness of their method of oxygen determination.[11] Their experimental melts, made in magnesia crucibles and under varying pressures of ($CO + CO_2$) mixture, were killed with aluminium, and the oxygen content was determined from the content of alumina found in the subsequently solidified metal. This method may lead to higher oxygen figures than are actually present in liquid metal, because aluminium dissolved in the melt could react also with iron oxide dissolved or absorbed in the walls of the magnesia crucible and with ($CO + CO_2$) gas. The present authors consider that this problem should be re-investigated before it can be regarded as finally solved, and they hope to carry out work in this connection in the near future.

As will be shown, the activity coefficient derived from acid open-hearth data leads to reasonably good agreement between the calculated and observed oxygen contents when applied to the essentially different conditions existing in the basic open-hearth furnace. The authors, therefore, feel justified in accepting, at present, that the effect of carbon on the activity coefficient of oxygen is as stated in Table II and Fig. 7 of this paper.

The accuracy of the oxygen content calculated by this method depends on the accuracy of the analytical determinations of FeO and Σa. On page 291 it was shown that the FeO content by analysis is, on average, slightly higher than the actual (equilibrium) FeO content. Therefore the calculated oxygen content will probably be somewhat higher than the actual content. The extent of this deviation may be judged qualitatively by comparing the FeO content by analysis with its corresponding equilibrium value. However, it is known that fluoride ions usually present in open-hearth slags increase the activity coefficient of ferrous ions[12] and this probably compensates for the slight error in the FeO determination.

In the following paragraphs, oxygen contents calculated from slag analyses by the semi-empirical method illustrated by Figs. 4, 5, and 7, have been compared with those determined in actual practice. The examples have been taken from the previous literature and from recent work in the Research and Development Department of The United Steel Companies, Ltd. In making these comparisons several factors should be borne in mind. Thus, some examples in the literature are not satisfactory if part of the data required for the calculations is not given. Moreover, a study of the literature reveals that the various methods used in practice for determining the oxygen in liquid steel are not all reliable. This is

Table II

ACTIVITY COEFFICIENT OF OXYGEN IN LIQUID STEEL AT VARIOUS CARBON CONTENTS

C, %	f_O
0	1·00
0·05	1·04
0·10	1·08
0·20	1·18
0·30	1·30
0·40	1·47
0·50	1·56
0·60	1·71
0·70	1·85
0·80	2·00
0·90	2·13
1·00	2·27
1·10	2·32
1·20	2·38

only to be expected, as suitable evidence from other sources has not been available for assessing the accuracy of the various sampling methods employed. The method of calculating oxygen contents from slag analysis (Figs. 4–7) provides a useful criterion for the various sampling methods for oxygen in liquid steel.

Table III shows a comparison of oxygen contents, calculated as outlined above, with those determined by Tenenbaum and Brown[13] using the bomb-test method. The data of Table III relate to tests taken before the addition of de-oxidizers to the bath (with the exception of test No. 14); as the temperature was not given, the oxygen content of liquid steel has been calculated for each of three possible furnace temperatures, *i.e.*, 1620°, 1600°, and 1580° C. Agreement of the calculated and observed oxygen contents is really close only at low carbon contents; at high carbon contents the observed oxygen values are lower than the calculated ones (*see* Fig. 8). This implies that the bomb-test method used by Tenenbaum and Brown gives somewhat low results.

Comparison of tests Nos. 13 and 14 also illustrates the possibility of low results by the bomb test; the tests were taken from the same heat, before and after addition of spiegel, respectively. Although test No. 14 shows a considerably higher oxygen content than test No. 13, it is unlikely that the oxygen content of the bath could increase to this extent as a result of deoxidation. It is possible, therefore, that bomb test No. 13 indicated only part of the oxygen present before the spiegel addition. Similar remarks can be applied to the recent work of Fornander,[14] who used a modified bomb method.

In the discussion on Tenenbaum and Brown's paper, Derge[13] pointed out that the oxygen contents of liquid steel obtained by the chilled-wedge method are higher than those from the bomb tests

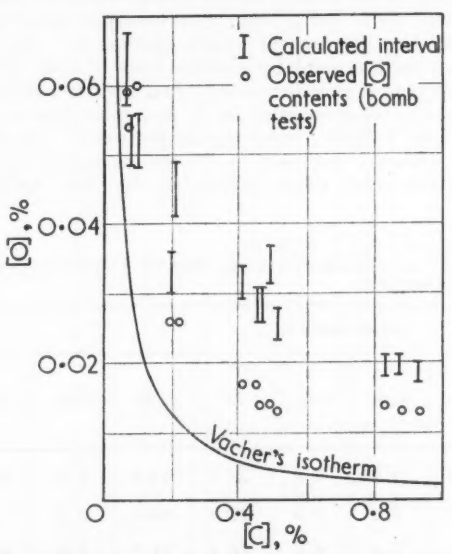

Fig. 8—Comparison of calculated and observed oxygen contents of liquid steel, for the data of Tenenbaum and Brown

Table III

DATA OF TENENBAUM AND BROWN

No.	Slag Analysis, %							Metal Analysis, %				[O] calculated for :			(S)/[S]	
	(FeO)	(Fe_2O_3)	(SiO_2)	(Al_2O_3)	(P_2O_5)	(Σa)	(CaO)	(MgO)	(MnO)	(S)	[C]	[Mn]	[P]	[S]	[O]	1620° C.	1600° C.	1580° C.	Observed	Calculated
1	18·0	6·0	14·8	2·8	1·9	18·5	37·6	9·5	7·6	0·13	0·07	0·13	0·009	0·025	0·059	0·068	0·062	0·057	5·0	4·9
2	14·2	6·0	15·6	3·1	2·5	20·0	38·5	9·3	9·5	0·11	0·08	0·18	0·012	0·024	0·054	0·056	0·052	0·048	4·5	5·3
3	15·4	5·1	14·2	3·0	2·4	18·4	38·5	10·6	9·1	0·09	0·10	0·20	0·012	0·024	0·060	0·056	0·052	0·048	3·7	5·8
4	9·5	3·8	17·4	3·5	2·6	22·2	45·1	10·0	6·6	0·15	0·20	0·23	0·016	0·026	0·026	0·036	0·033	0·030	6·0	6·2
5	14·7	5·0	14·5	3·9	2·0	19·2	42·6	9·3	6·9	0·15	0·21	0·17	0·010	0·028	0·026	0·049	0·045	0·041	5·3	5·7
6	11·6	2·8	16·7	3·4	2·1	21·3	46·5	9·2	6·0	0·17	0·41	0·18	0·010	0·028	0·017	0·034	0·032	0·029	6·3	5·8
7	10·8	4·2	16·0	3·7	2·7	21·1	45·9	9·2	6·0	0·18	0·45	0·19	0·012	0·029	0·017	0·031	0·029	0·026	6·2	6·2
8	9·5	3·8	17·4	3·5	2·6	24·2	45·3	10·0	6·6	0·15	0·46	0·21	0·014	0·030	0·014	0·031	0·029	0·026	5·0	4·7
9	14·3	4·3	14·1	3·9	2·2	19·0	44·6	9·0	6·0	0·20	0·49	0·15	0·008	0·026	0·014	0·037	0·034	0·031	8·3	5·9
10	12·4	3·6	14·6	4·4	2·6	20·2	46·8	7·5	5·3	0·20	0·51	0·14	0·009	0·027	0·013	0·028	0·026	0·023	7·4	6·2
11	9·1	4·4	18·8	3·3	2·6	23·4	42·4	8·3	9·9	0·14	0·83	0·27	0·016	0·028	0·014	0·021	0·020	0·018	5·0	5·5
12	8·8	3·4	19·7	3·5	2·7	24·6	42·0	7·1	11·1	0·15	0·88	0·29	0·018	0·028	0·013	0·021	0·020	0·018	5·5	5·3
13	10·2	4·4	16·6	3·6	3·1	21·8	45·9	7·9	7·6	0·18	0·93	0·24	0·015	0·031	0·014	0·020	0·019	0·017	6·0	5·9
14*	10·5	3·2	16·2	3·3	2·9	21·0	47·4	7·8	7·8	0·17	0·95	0·40	0·015	0·030	0·024*	0·020	0·019	0·017	5·7	6·4

* After addition of spiegel

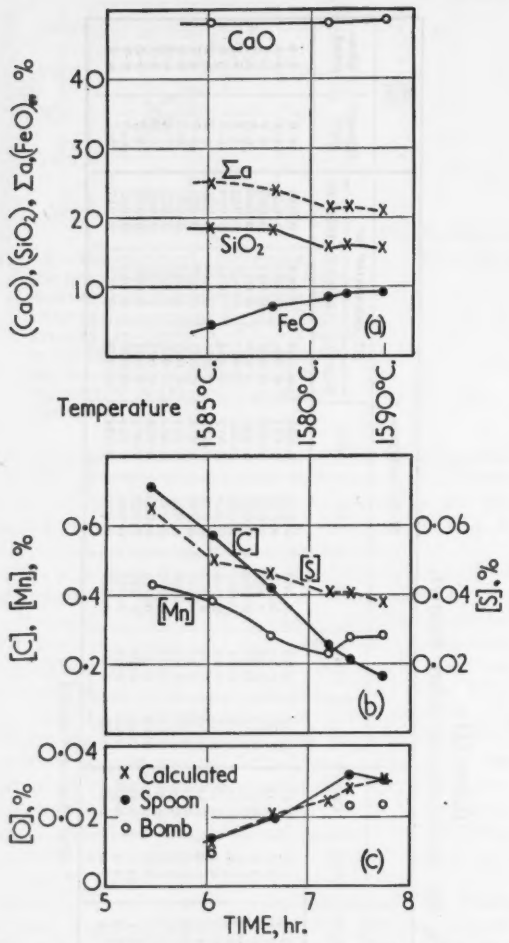

Fig. 9—Data for experimental heat V6956. (*a*) Slag, (*b*) metal, (*c*) oxygen

for samples taken before the addition of deoxidizers. After deoxidation with silico-manganese or with 15% ferro-silicon, the results by both methods agree well, especially for low carbons.

The cause of the lower results obtained by the bomb-test method is probably as follows: The reaction between carbon and oxygen is known to proceed very rapidly on the surface of solid iron. Liquid steel before entering into the bomb is in contact for a few seconds with the iron cap of the bomb, and this should lead to a partial depletion of the oxygen in steel. Decrease of oxygen content by this mechanism should be especially noticeable at higher carbon contents, and before the addition of deoxidizers.

Brower and Larsen[15] also have made a comparison of oxygen contents, in bomb samples and in samples killed with aluminium in a test mould. They found that the oxygen contents in the bomb samples were 0·010% lower, on the average, than in samples killed in the mould. Figure 8 shows a difference of this magnitude between the calculated oxygen contents and those found by Tenenbaum and Brown in bomb tests. This suggests that samples killed in the spoon—or, better still, partly in spoon and partly in mould—will give more reliable oxygen contents of liquid steel. In the spoon-killing method, however, the errors are more likely to occur with higher [O] values, particularly, if the slag is not removed well from the surface of liquid steel in the spoon.

Table IV gives the analytical data reported by Brower and Larsen[16] for three high-carbon heats, including the oxygen content determined in samples killed by aluminium in the spoon. The oxygen content calculated from slag analysis for 1550° and 1600° C. by means of Figs. 4, 5, and 7, agrees fairly well with the observed oxygen content.

Further confirmation of these views on the oxygen relationships in slag and metal has been provided by recent work in the authors' laboratories, on sampling methods for oxygen in liquid steel. As the details of this work when completed will be published elsewhere, reference will be made here only to those aspects relating to the subject of this paper. From a number of basic open-hearth heats, metal samples were taken simultaneously by the bomb method,[17,18] by the spoon method, and by modifications of both procedures. Slag samples were also taken, and the bath temperatures were recorded by an immersion pyrometer.

Table V gives a summary of the results obtained, and shows a comparison of the observed oxygen contents and those calculated by the methods

Table IV

COMPARISON OF OBSERVED AND CALCULATED OXYGEN CONTENTS FOR HEATS INVESTIGATED BY BROWER AND LARSEN

Heat	Metal Analysis, %				Slag Analysis, %								
	[C]	[O] Observed	[O] Calculated for: 1550° C.	[O] Calculated for: 1600° C.	(FeO)	(Fe_2O_3)	(SiO_2)	(Al_2O_3)	(P_2O_5)	(Σ*a*)	(CaO)	(MgO)	(MnO)
A	0·69	0·021	0·022	0·027	7·5	2·3	24·1	2·7	2·8	28·9	43·0	6·4	9·7
B	0·88	0·019	0·011	0·014	8·0*	5·2	14·8	2·2	3·3	18·9	50·9	5·0	9·5
C	0·60	0·020	0·018	0·021	11·9	3·7	11·0	2·4	1·9	14·4	51·7	7·0	8·6

* Too low—probably a sampling error. (FeO) calculated from the total iron content is 9·7%; this gives the calculated oxygen content of steel as 0·017% [O] at 1600° C., in better agreement with observation.

Table V

COMPARISON OF CALCULATED AND OBSERVED OXYGEN CONTENTS IN LIQUID BASIC OPEN-HEARTH STEEL DURING REFINING

Melt and Test No.	Temp., °C.	Metal Analysis, %							Slag Analysis, %										$\frac{(S)}{[S]}$	
		[C]	[Mn]	[S]	[P]	[O] Observed		[O] Calculated		(Fe)	(FeO) Calculated	(FeO)	(Fe_2O_3)	(SiO_2)	(Al_2O_3)	(P_2O_5)	(Σa)	(CaO)	(MgO)	(MnO)	(F)	(S)	Observed	Calculated
						Bomb	Spoon	I	II															
6916—1	1590	0·74	0·51	0·040	0·102	0·007	0·012	0·013	0·011	4·3	4·7	4·3	1·3	16·8	3·0	7·9	24·5	54·0	4·8	5·1	0·68	0·37	9·3	9·7
2	1628	0·28	0·29	0·034	0·019	0·020	0·019	0·025	0·024	7·7	6·9	7·4	2·8	14·6	2·5	6·9	21·5	51·1	6·6	5·6	—	0·30	8·8	8·7
3	1595	0·27	0·27	0·033	0·025	0·015	0·027	0·025	0·021	8·6	7·5	8·7	2·7	13·2	2·1	6·3	19·1	50·5	8·3	5·7	0·38	0·29	8·8	9·5
6918—1	1600	0·50	0·38	0·036	0·044	0·011*	0·014*	0·019	0·016	6·3	5·6	6·3	1·9	18·4	2·2	5·9	24·1	51·4	5·1	5·9	2·15	0·26	7·2	7·2
2	1600	0·30	0·31	0·033	0·037	—	0·024	0·021	0·022	6·9	6·6	6·4	2·7	17·4	2·1	5·4	22·7	50·2	7·0	6·0	—	0·26	7·8	8·6
4	1570	0·19	0·26	0·030	0·018	0·019	0·024	0·023	0·020	7·9	7·0	8·0	2·4	15·8	1·9	4·9	20·6	50·1	8·0	5·8	1·67	0·23	7·7	8·8‡
6922—1	1605	0·58	0·28	0·035	0·020	0·013*	0·014*	0·020	0·018	8·8	7·9	8·5	3·1	13·9	2·3	6·6	20·2	49·6	4·6	7·7	3·5	0·30	8·6	8·6
2	1590	0·41	0·29	0·031	0·024	—	0·025	0·021	—	8·4	—	—	2·4	13·7	2·4	6·2	19·7	—	—	—	—	0·30	9·7	9·3
5	1590†	0·29	0·25	0·031	0·022	0·014	0·026	0·025	0·021	—	8·2	9·8	3·3	11·9	2·1	5·6	17·3	52·8	4·0	6·8	2·8	0·30	9·7	10·2‡
6937—1	1572	0·40	0·45	0·044	0·019	0·009	0·018	0·012	0·012	7·0	5·5	5·5	3·5	12·5	2·9	4·9	18·2	55·5	4·4	5·7	3·6	0·49	11·2	16·5
2	1598	0·18	0·24	0·036	0·019	—	0·032	—	—	10·2	—	—	—	—	—	—	—	—	—	—	—	0·41	11·4	10·4
3	1600	0·10	0·15	0·037	0·012	—	0·046	0·043	0·040	—	13·5	14·5	6·3	10·2	2·1	4·1	14·7	46·5	6·2	6·2	—	0·34	9·2	8·5
4	1600	0·06	0·13	0·038	0·013	0·057	0·038	0·050	0·047	—	15·0	16·0	6·5	9·8	1·9	4·1	14·1	46·8	5·9	5·5	2·8	0·34	8·9	8·0
6941—2	1580†	0·65	—	0·033	—	0·012	—	0·013	0·011	—	5·6	5·9	2·5	14·4	2·6	6·9	21·1	53·7	4·5	6·1	3·3	0·40	12·1	11·5
3	...	0·62	0·37	0·033	0·037	—	0·020*	0·015	—	6·9	—	—	—	—	—	—	20†	—	—	—	—	0·40	12·2	11·3
4	1584	0·48	0·28	0·033	0·021	—	0·025	0·019	—	8·2	—	—	—	—	—	—	20†	—	—	—	—	0·37	11·2	10·2
5	1614	0·29	0·26	0·030	0·028	0·020	0·024	0·025	0·024	9·3	7·9	8·5	3·8	13·0	2·7	5·7	19·0	52·1	5·4	5·6	2·1	0·36	12·0	9·9
6951—5	1640	0·09	0·15	0·032	0·024	—	0·035	0·043	0·040	10·5	9·6	10·7	3·3	15·2	1·7	4·6	19·6	47·7	5·9	4·4	—	0·14	4·4	7·3
7	...	0·10	0·11	0·031	0·012	0·041	0·043	0·055	0·048	14·0	13·1	14·7	3·9	13·0	1·7	3·6	16·8	43·4	9·5	4·4	1·4	0·14	4·5	7·0
6954—1	1550	0·73	0·33	0·052	0·030	0·007	0·011*	0·011	0·011	6·7	6·4	6·3	2·5	16·2	1·9	6·6	22·1	47·5	5·2	8·1	1·6	0·27	5·2	9·4
4	1560	0·35	0·26	0·042	0·023	—	0·029	0·019	0·018	—	7·6	7·8	3·4	16·2	1·7	6·0	20·4	48·2	4·7	7·5	—	0·24	5·7	9·3
6	1600	0·17	0·30	0·037	0·027	0·030*	0·033*	0·028	0·027	8·6	7·9	8·2	3·2	16·0	1·8	5·8	20·3	48·0	5·3	7·7	1·3	0·24	6·5	9·0‡
6956—1	1585	0·57	0·38	0·050	0·071	0·010	0·014	0·012	0·013	5·0	4·8	4·6	1·7	18·5	2·6	6·6	25·0	48·0	4·4	7·9	1·3	0·25	5·0	8·3
2	...	0·41	0·28	0·046	0·030	—	0·020	0·021	—	7·1	—	—	—	18·2	2·2	6·5	24·3	—	—	—	—	0·23	5·0	7·0
3	1580	0·25	0·23	0·040	0·019	—	—	0·025	0·026	9·0	8·7	8·3	3·7	15·5	2·2	6·2	21·4	48·0	4·2	7·7	—	0·22	5·5	7·7
4	...	0·21	0·27	0·040	0·020	0·023	0·032	0·028	—	9·3	—	—	—	16·0	1·8	6·0	21·4	—	—	—	—	0·22	5·5	7·0
5	1590	0·16	0·28	0·038	0·024	0·023	0·030	0·030	0·029	9·5	8·6	9·2	3·3	15·5	1·8	5·8	20·8	48·4	4·0	7·7	0·8	0·23	6·1	7·4‡
6967—2	1565	0·73	0·44	0·039	0·076	0·010*	0·013*	0·009	0·010	4·1	4·6	4·2	1·8	19·5	2·5	6·3	25·7	49·6	4·4	8·1	2·1	0·29	7·4	8·3
4	1610	0·05	0·11	0·030	0·014	0·069	0·067	0·051	0·055	17·6	16·2	14·5	9·2	12·5	2·2	3·9	17·0	43·4	—	5·7	—	—	—	—
5	1626	0·03	0·07	0·030	0·011	0·087	—	0·072	0·072	24·3	22·5	22·7	9·7	10·3	1·6	3·2	13·8	38·4	5·6	4·8	1·3	0·17	5·7	6·0
5a	1626	0·03	0·06	0·030	0·010	0·075	0·081*	0·072	—	23·7	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7189—1	1558	0·26	0·25	0·038	0·018	0·018	0·036	0·018	0·019	8·2	7·8	7·6	3·4	13·8	1·8	4·9	18·5	44·8	4·4	7·1	—	0·26	6·8	11·6
2	1576	0·14	0·19	0·033	0·013	0·030	0·034	0·032	0·028	11·9	10·4	11·8	3·9	12·0	1·8	4·6	16·5	46·7	3·7	6·7	—	0·27	8·2	9·1
3	1500	0·12	0·19	0·033	0·013	0·031	0·029	0·038	0·038	13·6	13·8	13·8	4·1	11·9	1·8	4·3	16·1	46·8	2·6	6·6	—	0·27	8·2	8·0
7196—1	1570†	0·52	0·25	0·042	0·034	0·011	0·016	0·011	0·016	6·7	6·9	4·5	5·1	16·6	2·3	5·7	22·4	48·9	2·9	6·0	—	0·29	6·9	13·0
2	1597	0·13	0·16	0·036	0·016	0·031	0·035	0·028	0·031	11·4	10·0	8·9	6·5	14·5	2·0	4·6	17·2	49·3	4·3	5·4	—	0·25	6·9	9·3
3	1600	0·12	0·18	0·032	0·017	0·030	0·027	0·038	0·034	13·2	11·4	12·8	4·6	12·0	1·6	4·3	16·2	47·1	3·1	6·4	—	0·27	8·4	8·5

* Oxygen content determined by gravimetric method
† Values estimated by interpolation
‡ 17–23 minutes after addition of spiegel

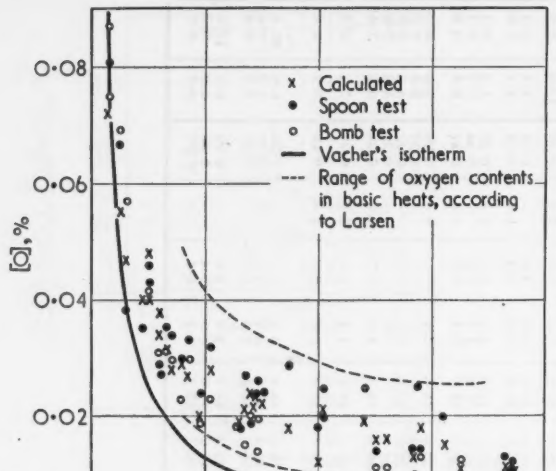

Fig. 10—Oxygen contents in basic liquid steel, determined by bomb and spoon methods and calculated from slag analysis and carbon content

described in this report. (Two values are given for the calculated oxygen content, *i.e.*, columns I and II. Column I was obtained by using the slag FeO content as found on analysis, whilst column II is founded on the 'equilibrium' FeO content as derived from the total iron content (Fig. 2). The agreement between both sets of values is good, although the analytical FeO value gives, in general, slightly higher calculated oxygen values, as would be expected.) The bomb-test oxygen results are generally lower, and the spoon-test results generally higher, than the calculated oxygen values. This is illustrated also by Fig. 9, which shows the changes in composition during the course of a basic open-hearth heat.

Figure 10 represents a plot of carbon content against the observed and calculated oxygen contents from the results in Table V. The points all lie above the C–O equilibrium isotherm, in the region found by Larsen[19] and other investigators.

Considering the possible errors in the theoretical calculation of oxygen content and in the methods of sampling and analysis, the agreement between the calculated and observed oxygen contents is such as to support the view that the distribution of oxygen between slag and metal is governed by the same equilibrium laws as in laboratory experiments with carbon-less melts. The presence of carbon in the open-hearth steel modifies these laws by changing the activity coefficient of oxygen dissolved in liquid steel.

The authors do not propose to discuss in detail the kinetics of the carbon–oxygen reaction which was elucidated in essential points by Körber and Oelsen.[20] They have shown that the evolution of carbon monoxide (the formation of gas bubbles) requires the presence of catalysers and proceeds at a measurable rate only on the surface of the furnace hearth. Goodeve[21] indicated recently, from considerations of molecular kinetics, that the reaction between carbon and oxygen atoms in homogeneous liquid metal must proceed almost instantaneously to the equilibrium in the metal phase. The carbon monoxide formed remains in supersaturated solution, and therefore the carbon–oxygen equilibrium corresponds to a higher pressure of CO than the total pressure in the open-hearth bath. Since the solubility of molecular carbon monoxide in liquid metal must be extremely small—as it is for all di-atomic molecules—the presence of CO in homogeneous solution, even at high supersaturation, will not practically affect the content of uncombined oxygen atoms determined by the usual analytical methods.

The carbon–oxygen reaction can be represented as proceeding in two steps :

$$\underset{\text{I}}{C_{metal} + O_{metal}} \rightleftharpoons \underset{\text{II}}{CO_{metal}} \rightarrow CO_{gas}$$

The first step attains equilibrium almost instantaneously ; the second proceeds only at an interface such as the furnace walls, and is far from equilibrium in the open-hearth furnace. This lack of equilibrium of the carbon–oxygen reaction with respect to the gaseous phase need not affect the equilibria of all reactions taking place between slag and metal. On the contrary, the mechanical action of carbon monoxide evolved during the boil will assist these reactions to attain equilibria more rapidly, and the liberation of carbon monoxide gas may effectively protect the slag and metal from the oxidizing action of furnace gases.

DESULPHURIZATION IN THE BASIC OPEN-HEARTH FURNACE

According to earlier theories, the transfer of sulphur from metal to slag was usually described as a consequence of the following reactions :

$$FeS_{metal} = FeS_{slag}$$

$$FeS_{slag} + CaO_{slag} = FeO_{slag} + CaS_{slag}$$

The formation of CaS was thought necessary to hold sulphur in the slag, and therefore the presence of 'free' lime was considered essential.

In the ionic theory, specific interaction between calcium and sulphur is not assumed. An addition of lime as well as of any other base (*e.g.*, MnO or MgO) has a twofold effect : (i) the content of free oxygen ions is increased, and (ii) the content of Fe^{++} ions is decreased by dilution. Both circumstances are favourable to the desulphurization, as is evident from the principal equilibrium equation :

$$\frac{(S'')}{[S]} = k\,\frac{(O'')}{[O]}$$

The dilution of Fe^{++} ions in the slag leads to a decrease of oxygen in the metal, because these quantities are correlated by the equation :

$$[O] = \frac{(Fe^{++})}{A(O'')^{\frac{1}{2}}}$$

The belief that only lime was operative in sulphur removal has been very strong. This was presumably because, in present basic steelmaking practice, lime was the only basic constituent which could be varied as required. Owing to the limited solubility of MgO,

its content in basic slag is appreciably smaller than that of CaO, and being practically constant its contribution to sulphur removal was generally overlooked.

The equilibrium ratio

$$k_S^O = \frac{[S](O'')}{[O](S'')}$$

is of limited value for practical calculations, because the oxygen content of liquid steel is not always available. Furthermore, the activity coefficient of oxygen varies considerably with the carbon content of liquid steel. On the other hand, the relationship derived in Part I, *i.e.*,

$$\frac{(Fe{+}{+})(S'')}{[S]} = 0{\cdot}043(O'')^{8/2},$$

provides a more convenient means of calculating the sulphur distribution ratio from the slag analysis. By replacing the ionic fractions in the above equation by the corresponding weight percentages of FeO and Σa, a nomogram (Fig. 11) has been prepared, which shows the dependence of the (S)/[S] ratio on the contents of FeO and Σa in slag.

Figure 11 has been used to obtain calculated desulphurization ratios for comparison with those found by direct analysis. Table III gives this comparison for the data of Tenenbaum and Brown, and Table V for a series of heats examined by the present authors. In view of the possible inaccuracies in routine determinations of the ferrous oxide content, the agreement can be considered satisfactory.

Carbon has been found to have no perceptible influence on the sulphur distribution ratio. Thus, up to about 1% of carbon the activity coefficient of sulphur in liquid steel can be regarded as practically independent of the carbon content. Kitchener, Bockris, and Liberman,[22] in a recent investigation on the activity of sulphur in liquid iron, found that the activity coefficient of sulphur is approximately doubled when iron is saturated with carbon. Results obtained by the present authors indicate that any variation in the activity coefficient of sulphur at lower carbon contents, up to about 1% of carbon, is small and can be neglected for practical purposes. Thus, the sulphur distribution ratio can be calculated, by the relationships described in this paper, to an accuracy within 10% of the actual value. If the activity coefficient of sulphur increases by 10–20% when the carbon content approaches 1%, the effect on the sulphur distribution ratio would not be noticeable. Carbon appears to have a considerably less pronounced effect on the sulphur activity than on oxygen activity.

The estimation of the sulphur distribution ratio by means of Fig. 11 can be applied also to extreme cases, *e.g.*, slags with very low acid contents and steels with high carbon contents, provided that there is an equilibrium between slag and metal. Some

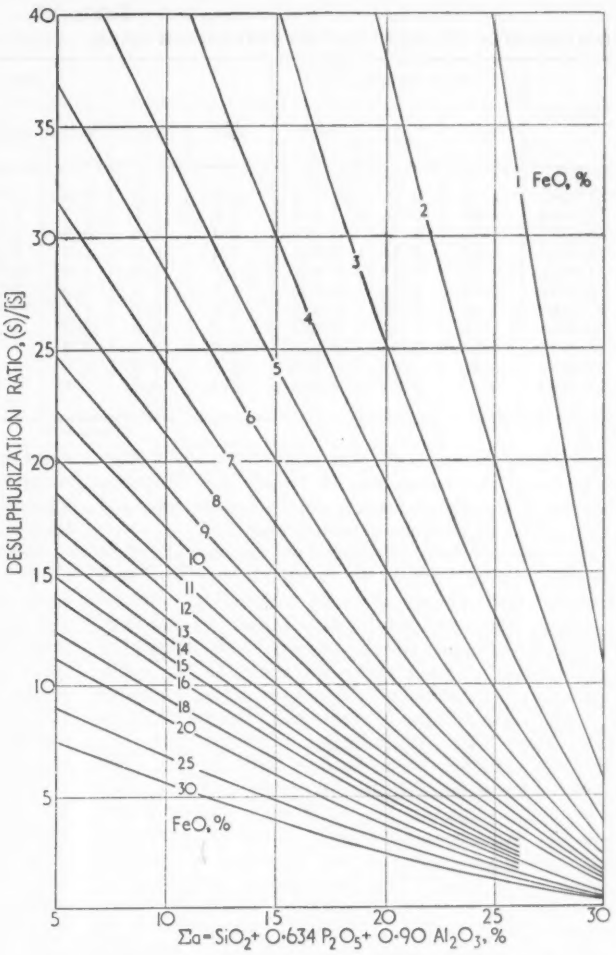

Fig. 11—Nomogram for estimation of the sulphur ratio

such examples are given in Table VI, which shows a comparison of observed and calculated sulphur distribution ratios for data provided by Manterfield.[23] The data refer to alloy recovery casts made in 1940 ; charges of alloy steel turnings, lime, anthracite, coal, fluorspar, and some ferro-manganese were melted and tapped with little or no additional feed or refining. The data were not fully complete : thus only the total iron content in slag was available, and the FeO content had to be estimated by means of Fig. 2. The value for the acid content, Σa, includes an assumed figure of 2% for the Al_2O_3 content, which was not reported. Moreover, the very high contents of lime reported in some slags indicate that a considerable proportion of a solid lime phase was present. The calculated and observed sulphur distribution ratios are of a similar order of magnitude, and in view of the wide range of sulphur distribution ratios covered the agreement must be considered satisfactory.

Manterfield's data indicate that desulphurization ratios much higher than 10 are possible in basic open-hearth furnace practice, provided that the

Table VI

COMPARISON OF CALCULATED AND OBSERVED SULPHUR RATIOS FOR THE DATA OF MANTERFIELD

Cast No.	Metal Analysis, %			Slag Analysis, %								(S)/[S]	
	[C]	[Mn]	[S]	(FeO)	(SiO_2)	(P_2O_5)	(Al_2O_3)*	(Σa)	(CaO)	(MnO)	(S)	Observed	Calculated
31/9066	2·30	0·96	0·024	2·8	14·0	0·4	2·0	16·0	56·0	2·4	0·50	21	37
37/3044	2·45	0·96	0·019	5·1	8·7	1·2	2·0	11·2	60·8	3·7	0·85	45	31
35/6287	2·26	1·18	0·018	4·2	6·9	0·9	2·0	9·1	60·2	2·4	0·68	38	42
24/5725	2·27	0·94	0·021	7·4	6·1	1·1	2·0	8·5	61·6	3·6	0·54	26	25
31/9181	2·00	0·84	0·022	15·0	7·0	1·0	2·0	9·3	58·1	6·2	0·29	13	12
30/3791	2·88	1·02	0·023	4·8	14·8	1·5	2·0	17·4	57·4	4·4	0·63	27	22
31/9189	2·56	0·98	0·020	6·6	10·7	1·1	2·0	13·1	54·9	5·7	0·39	20	22
36/4913	1·36	1·30	0·021	3·4	15·5	0·9	2·0	17·8	58·8	3·4	0·43	21	26
26/4119	1·90	0·93	0·030	8·4	13·9	0·9	2·0	16·1	52·6	6·9	0·41	14	15
37/3098	2·60	1·07	0·016	10·5	4·6	0·9	2·0	6·9	60·2	4·8	0·33	21	18
23/2982	2·32	1·11	0·018	3·3	13·1	1·0	2·0	15·5	57·3	4·7	0·56	31	34

* Estimated

contents of acids and of FeO in the slag are sufficiently low. The conclusion of Grant and Chipman that the best sulphur ratio is only 8 can be regarded as the result of their incomplete theory.

The concentrations of sulphur in slag and metal in the open-hearth furnace are comparatively low, and therefore both phases must be thoroughly agitated to attain the equilibrium distribution of sulphur. Figure 12 represents the comparison of the calculated and observed sulphur ratios for the data of Tenenbaum and Brown and for the data compiled in Table V. The data of Tenenbaum and Brown refer to tests taken before the addition of deoxidizers, *i.e.*, after the bath has been ' worked out ' by boil. The agreement is good, with two exceptions. In the data of Table V, shown in Fig. 12 as open circles, points from the same heat have been joined by arrows, so that the arrow indicates the sequence of samples during each heat. The discrepancy between the calculated and observed sulphur ratios decreases towards the end of heat. Similar changes have been confirmed in many other published data. Agitation of bath, therefore, is very important for the establishment of sulphur equilibria. It is, of course, an obvious requirement for all heterogeneous equilibria, and must always be borne in mind in both practical and theoretical considerations of slag–metal reactions.

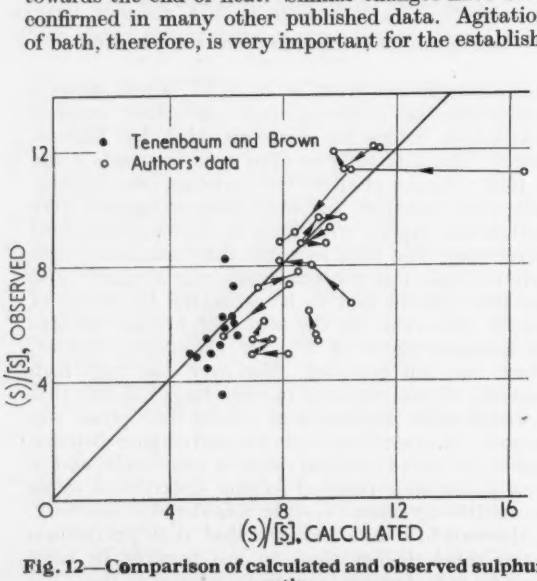

Fig. 12—Comparison of calculated and observed sulphur ratio

The nomogram, Fig. 11, can be applied also to the oxidation period in the basic electric-arc furnace, again provided that the metal and slag are sufficiently well agitated. In the absence of boiling, close agreement between the calculated and observed sulphur ratio is not expected. Recent work by Mowat[24] shows that, in the production of rimming steel in the electric-arc furnace, the desulphurization ratio was sometimes appreciably higher than that expected from slag analysis. The bath, in these circumstances, was practically free from boiling, and therefore the slag below the electrodes could even revert to a reducing condition, and could thus extract sulphur from the metal more effectively than the overall slag composition would imply. The reducing nature of the slag under the electrodes is made probable—as Mowat reports—by the occurrence of calcium carbide in such slags. This would hardly be possible for a homogeneous oxidizing slag.

SULPHUR RATIOS OBTAINABLE IN THE BASIC OPEN-HEARTH PROCESS

According to the foregoing, the factors determining the position of sulphur equilibrium are the content of FeO, and the acidity of slag. These two factors are, however, mutually interdependent. Schleicher[25] has found that for basic open-hearth slags the content of FeO decreases as the content of $SiO_2 + P_2O_5$ increases. Schleicher claimed initially that there existed a linear relationship between the content of FeO and the sum $SiO_2 + P_2O_5$. The agreement of actually observed data with this statement is very poor. The authors consider it more accurate to subdivide the empirical data into several groups and to represent the dependence of the FeO content on the sum of acid constituents ($\Sigma a = SiO_2 + 0{\cdot}634P_2O_5 + 0{\cdot}90Al_2O_3$) for each group separately. After examining numerous published slag analyses, the authors have found sufficient data for the following two groups : (i) slags with low P_2O_5 content (up to about 3% of P_2O_5) ; and (ii) slags with medium

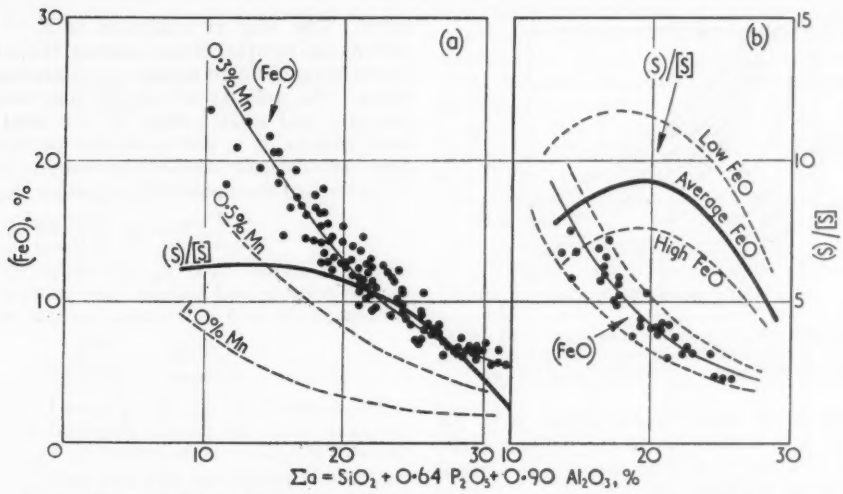

Fig. 13—Effect of slag acidity on the FeO content and the sulphur ratio. (*a*) Slags with low P_2O_5 content. The curve of sulphur ratios is drawn only for melts containing 0·30% residual manganese. (*b*) Slags with 4–10% of P_2O_5 and about 1% of fluorine. Dotted curves indicate the spread of FeO contents; dashed curves indicate the spread of sulphur ratios

P_2O_5 content (4–10% of P_2O_5). The dependence of the FeO content on Σa follows a similar but not identical course for these two groups, as is seen from Figs. 13*a* and *b*. The scatter of points in each diagram may be caused by analytical errors, insufficient approach to equilibrium, temperature variations, differences in the manganese content in the bath, and the presence of varying amounts of fluorspar. It is impossible to assess quantitatively the effects of these several factors, because the temperatures and the contents of fluorine are seldom reported. The effect of residual manganese content in the metal is especially noticeable for group (i), for which the published data are more numerous than for the other group. The increase of the residual manganese content in the metal displaces the curve of FeO contents to lower values. In Fig. 13*a* only the points corresponding to 0·30 ± 0·10% of residual manganese were plotted, to avoid overcrowding. The course of the curves for 0·5% and 1% of Mn is indicated by dashed curves. The data in Fig. 13*b* refer to slags with 4–10% of P_2O_5 and normal residual manganese contents of about 0·25 ± 0·10% of Mn; the two dashed (FeO) curves in this diagram represent the approximate limits of spread.

The empirical relationships of this type were explained by White[26] as being due to the solubility relationships in basic slags, which tend to reach equilibrium with several solid phases. This explanation may, perhaps, be better re-stated in terms of the Phase Rule. Assuming that temperature and pressure are approximately constant, the Phase Rule equation may be written as follows :

$$F = C - P,$$

where F = number of degrees of freedom
C = number of components
P = number of phases.

The number of components in basic slag is at least seven, *viz.*, Fe, Mn, Si, P, O, Ca, and Mg. Figures 13*a* and 13*b* show that the content of FeO in slag is a function of SiO_2 and P_2O_5 in the slag and of Mn in the metal; thus there are three degrees of freedom. Therefore the system must have four phases, *i.e.*, there must be a fourth phase (in addition to the known three : liquid metal, liquid slag, and solid furnace lining) with which all other phases are in, or are very near to, equilibrium. This fourth phase may be either solid lime or some other crystalline phase. Since the number of components may be larger than seven (owing to the presence of variable amounts of alumina, fluorspar, and other substances), the empirical relationships of the type shown in Figs. 13*a* and *b* cannot be expected to be very accurate. Nevertheless, they can be useful for the derivation of broad practical conclusions.

The close relation between FeO and Σa for each group shown in Figs. 13*a* and *b* can be used to determine what average sulphur ratio can be expected according to the nomogram, Fig. 11, for a slag of given composition. Thus the solid curve in Fig. 13*a* represents the average sulphur ratios determined, by means of the nomogram, from the average contents of FeO and Σa in the slag for open-hearth heats with about 0·30% of residual manganese in the metal. The best average sulphur ratio, (S)/[S] = 6·5, is attained in this case at about 15% Σa; sulphur ratios for higher manganese contents in the metal will be correspondingly higher. (An example of this is shown in the data of Manterfield, reported in Table VI.) The dilution of acids below about 15% Σa by addition of lime will not improve the sulphur ratio.

A better average sulphur ratio can be obtained for slags with medium content of P_2O_5, shown in Fig. 13*b*, because the curve of average FeO contents is lower in this case than the curve for 0·3% of residual manganese in Fig. 13*a*. The optimum average sulphur ratio, (S)/[S] = 9·3, for slags with medium contents of phosphoric acid, is attained at about Σa = 20%.

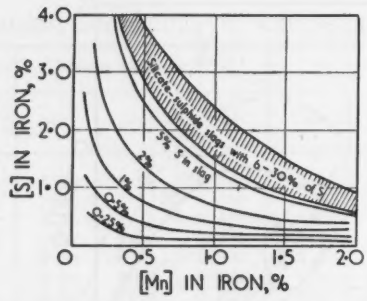

Fig. 14—Distribution of sulphur between acid FeO–MnO–SiO_2 slags and liquid iron. Melts in silica crucibles. Experiments by Körber and Oelsen[27]

Further dilution of acids below about 20% Σa may result even in a decrease of the sulphur ratio, because such dilution leads automatically to a rapid increase of FeO in the basic slag.

DESULPHURIZATION IN THE BLAST-FURNACE AND IN THE ACID OPEN-HEARTH FURNACE

Although blast-furnace slags are either acidic or slightly basic—substantially less basic than normal basic open-hearth slags—they may achieve considerable desulphurization. Owing to lack of essential data, it is not possible, as yet, to elucidate the atomic structure of blast-furnace slags and to derive the equilibrium laws governing the reactions of the various complex silicate and alumino-silicate irons. Nevertheless, it is believed that even acid slags may contain a small content of oxygen ions, and that consequently the principal sulphur–oxygen equilibrium may be applied also to:

$$\frac{(O'')\,[S]}{[O]\,(S'')} = k_s^o.$$

From this it follows that the desulphurization ratio (S″)/[S] will depend on the activity of oxygen in the metal and on the activity of oxygen ions in the slag.

The work of Körber and Oelsen[27] on the sulphur distribution between acid slags and metal in silica crucibles provides useful data for consideration of the sulphur reactions in blast-furnace slags. Consider first a comparatively simple example of sulphur distribution, between acid slags of the system FeO–MnO–SiO_2 and metal in equilibrium with solid silica. The slag is composed of Fe^{++} and Mn^{++} cations and complex silicate anions, the activity of the latter being constant owing to equilibrium with solid silica. The activity of oxygen ions would also be constant and small. Since N, the total number of ions, cancels, it is not necessary to determine the true ionic concentration of the reacting ions present; the principal desulphurizing equation thus becomes:

$$\frac{\%\ S''_{slag}}{\%\ S_{metal}} = k_s^o\ \frac{\%\ O''_{slag}}{\%\ O_{metal}}.$$

The % S''_{slag} and % O''_{slag} indicate percentage weight of free sulphur and oxygen ions in slag. Since the content of O″ ions is constant, we can write:

$$\frac{\%\ S''_{slag}}{\%\ S_{metal}} = \frac{k'^{S}_{O}}{\%\ O_{metal}}.$$

The constant k'^{S}_{O} can be estimated with reasonable accuracy from the results obtained by Körber and Oelsen, which are summarized in Fig. 14. For low contents of sulphur in slag and metal (*i.e.* <1% of S in each phase), the oxygen contents of the metal can be calculated from the earlier work of Körber and Oelsen[28] on the oxygen content of metal under FeO–MnO–SiO_2 slags saturated with silica.

The necessary data for the calculation of the constant k'^{S}_{O}, and the results obtained for a few examples, are given in Table VII. The values of k'^{S}_{O} calculated from the above equation are reasonably constant. The mean value of k'^{S}_{O} (*i.e.*, 0·2) may now be used to calculate the sulphur distribution ratio at higher silicon and lower oxygen contents, by assuming, as a first approximation, that the activity coefficient of silicon remains constant up to 3% of Si.

The result of these calculations is shown in Fig. 15, where the MnO content in the slag, the oxygen content in the metal, and the sulphur ratio are plotted against the silicon content. This diagram shows that considerable desulphurization of metal of high silicon content can be attained by acid FeO–MnO–SiO_2 slags saturated with silica.

It is obvious that desulphurization by blast-furnace slag follows similar lines. Probably MnO is replaced by CaO (and partly by Al_2O_3), and SiO_2 is supplemented by Al_2O_3. (Aluminium probably occurs in blast-furnace slags partly as complex alumino-silicate ion and partly as Al^{+++} ion.) Blast-furnace slags are not saturated with silica, therefore higher activity of oxygen anions, and higher desulphuriza-

Table VII

COMPOSITION OF METAL AND SLAG IN EQUILIBRIUM WITH SOLID SILICA

Metal Analysis, %				Slag, % (S)	Sulphur Partition (S)/[S]	$k'^{S}_{O} = \frac{(S)/[O]}{[S]}$
[Mn]	[Si]	[O]	[S]			
0·20	0·04	0·029	0·40	0·25	0·62	0·18
0·20	0·04	0·029	0·80	0·50	0·62	0·18
0·40	0·11	0·018	0·22	0·25	1·13	0·20
0·40	0·11	0·018	0·45	0·50	1·1	0·20
0·40	0·11	0·018	0·90	1·00	1·1	0·20
0·60	0·22	0·013	0·15	0·25	1·7	0·22
0·60	0·22	0·013	0·35	0·50	1·4	0·18
0·60	0·22	0·013	0·67	1·00	1·5	0·19
						Average 0·20

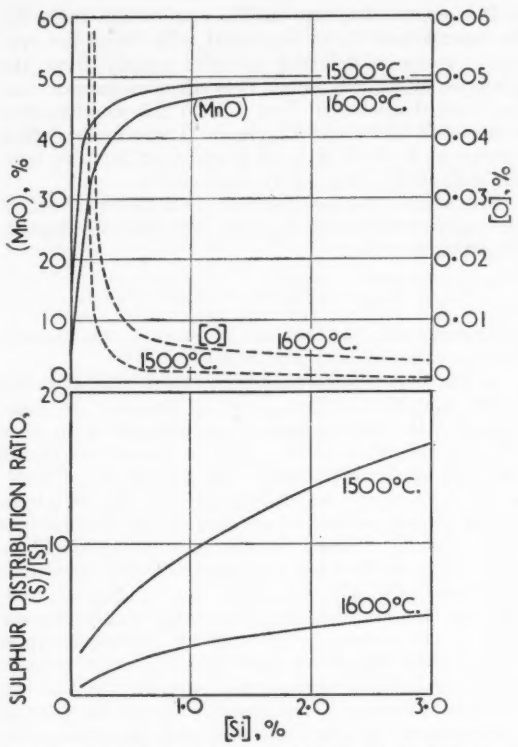

Fig. 15—Desulphurization by acid FeO–MnO–SiO_2 slags

tion than is indicated in Fig. 15, may be expected. Moreover, Körber and Oelsen's work[29] indicates that the activity coefficient of silicon increases with increasing silicon and carbon contents. Therefore, a lower content of silicon than is indicated in Fig. 15 will suffice to reduce the oxygen content in the metal, and so will favour the desulphurization.

Although the desulphurization by acid slags should be greater at lower temperatures, as is indicated in Fig. 15, it must be remembered that high temperature favours the reduction of silicon, and that an increase in the silicon content (corresponding to a decrease of oxygen content) is a prerequisite for an efficient desulphurization.

These considerations are sufficient to provide a qualitative picture of desulphurization in the blast-furnace. To obtain quantitative relationships, direct measurements of equilibria would be necessary. Such measurements should answer, also, the question whether sulphur is present in acid slag in the form of simple anions only, or also as complex anions with silicon or aluminium central atoms. The latter possibility cannot be excluded *a priori*.

After this paper was completed there was published a very important work by Hatch and Chipman,[30] who have investigated the equilibria between synthetic blast-furnace slags and iron in graphite crucibles heated by induction and held for seven hours at a constant temperature (1425° and 1500° C.) under carbon monoxide atmosphere. In such conditions the activity of oxygen, as well as that of carbon, would be practically constant. The variations in the sulphur ratio should therefore reflect the variations in the activity of oxygen ions in slag. Hatch and Chipman found that the sulphur ratio in this system can be represented as a function of 'excess base,' defined as $(CaO + \frac{2}{3}MgO) - (SiO_2 + Al_2O_3)$ in mols per 100 g. of slag (*see* Fig. 16*a*).

A similar correlation exists between the sulphur ratio and the sum of acids $\Sigma a = SiO_2 + 0{\cdot}9Al_2O_3$ in weight per cent., as used in this paper (*see* Fig. 16*b*). Both definitions of basicity or acidity are only approximate, and Figs. 16*a* and *b* show that both can be used for rough estimation of sulphur equilibria in the blast-furnace. The experimental data show that sulphur ratio depends on the total content of sulphur in slag : the apparent effect of the increased content of sulphur is equivalent to a certain increase in the content of oxygen ions, because the following equation is applicable to this system :

$$\frac{(S'')}{[S]} = k''^{S}_{O}(O'').$$

The increase in the content of oxygen ions in slag may result from reaction of aluminate ions (or silico–aluminate ions) with sulphur ions, according to the general formula :

$$\{AlO_n\} + nS'' \rightleftharpoons \{AlS_n\} + nO'',$$

where the symbols in brackets represent complexes of aluminium with oxygen and sulphur ions respectively. Further, the ionic effect of the increased

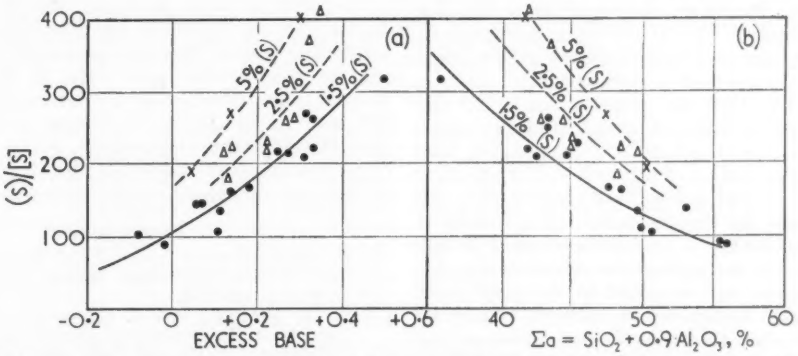

Fig. 16—Effect of excess base and 'acidity' on sulphur ratio at 1500° C., for 1·5–5% sulphur slags. (*a*) Excess base, (*b*) 'acidity'

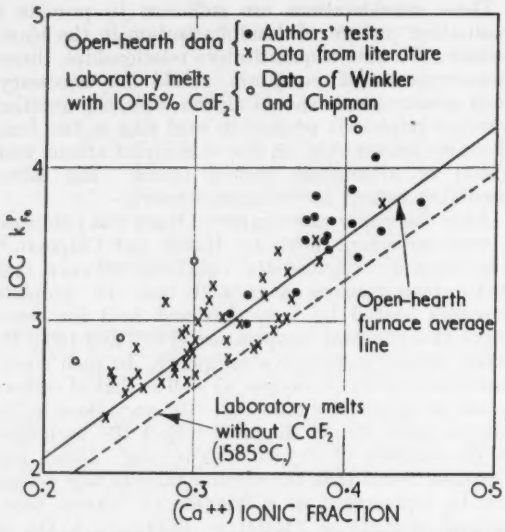

Fig. 17—Phosphorus equilibrium ratios for open-hearth furnace tests

sulphur content might be attributed to the displacement of the equilibria :

$2SiO_4'''' \rightleftharpoons Si_2O_7'''' + O''$, $3SiO_4'''' \rightleftharpoons Si_3O_{10}'''' + 2\,O''$, etc., from left to right. The question of which of these reactions takes place or predominates in blast-furnace slags cannot yet be answered.

PHOSPHORUS EQUILIBRIA

In Part I it was shown that the phosphorus equilibria could be expressed by the following equation :

$$\log k^P_{Fe} = \log \frac{(PO_4''')}{[P](Fe^{++})^{5/2}(O'')^{1/4}}.$$

This expression has been applied to a large number of open-hearth slag and metal analyses from previous literature and from the authors' own recent experiments. In Fig. 17 the logarithms of the phosphorus equilibrium ratios, log k^P_{Fe}, derived from these data are plotted against the content of calcium ions.

Most of the data from the literature give no indication of the temperature ; but, since the tests were taken mostly in the latter stages of the refining period (*i.e.*, before the addition of deoxidizers), it is reasonable to assume an average temperature of 1580 ± 30° C. Therefore, the equilibrium line for 1580° C. derived from the laboratory experiments of Quarrell and others has been included in the same diagram (Fig. 17), for ease of comparison.

Figure 17 shows that the values of log k^P_{Fe} for the open-hearth tests depend on the content of Ca^{++} ions, in a similar manner to the data from laboratory experiments. The spread of points is slightly greater, and the values of log k^P_{Fe} are generally higher, than the equilibrium value for the synthetic melts. Most of the tests in Fig. 20 had a low carbon content (0·05–0·4%) ; however, no systematic trend of log k^P_{Fe} value with carbon content could be detected, even for samples with a higher carbon content. It may be concluded, therefore, that the effect of carbon on the activity of phosphorus in open-hearth steel is either non-existent or comparatively small.

The general increase in the equilibrium ratio k^P_{Fe} for open-hearth tests compared with those for synthetic melts is believed to arise mainly from the presence of fluoride ions. This effect of fluoride ions has been discussed in Part I for a few experimental melts of Winkler and Chipman. These melts, which contained 0·10–0·18 ionic fraction of fluoride ions, are indicated in Fig. 17 by open circles.

The actual physico-chemical mechanism by which the equilibrium ratios k^P_{Fe} and, therefore, the dephosphorization ratio :

$$\frac{PO_4'''}{P} = k^P_{Fe}\,(Fe^{++})^{5/2}(O'')^{1/4},$$

are increased in the presence of fluoride ions, requires further experimental investigation.

It has been shown that both the desulphurization ratios and the oxygen contents obtained in basic open-hearth practice agree satisfactorily with data derived from fluoride-free melts. Since both (S)/[S] and [O] are proportional to the first power of Fe^{++} content, they will be less sensitive to the variations in the activity of Fe^{++} ions produced by fluoride ions than will k^P_{Fe}, which is inversely proportional to $(Fe^{++})^{5/2}$. In Part I it was suggested that, as well as increasing the activity coefficient of ferrous ions, fluoride ions may influence the total equilibrium content of phosphorus in the slag by forming complex anions with phosphate ions. The dephosphorization ratio would then depend not only on the absolute content of fluorine in the slag but also on the position of equilibria between fluoride and phosphate ions. However, the existing data are not sufficient to make quantitative conclusions.

The experiments with synthetic fluoride-free slags must be regarded as giving the lower limit of the dephosphorization ratio, which is usually greatly exceeded in actual open-hearth practice because of the presence of fluorides.

For steelplants using a standardized method of steelmaking and uniform raw materials, the deviations from the theoretical dephosphorization ratio (valid for fluoride-free slags) can be accounted for by applying a constant correction factor. A more detailed discussion of the phosphorus equilibria is reserved for a later publication.

Acknowledgments

The authors wish to thank Mr. F. H. Saniter, Director of the Research and Development Department, The United Steel Companies, Ltd., for permission to publish this paper ; Mr. D. Manterfield for private communication of his data ; and members of the staff of the Chemical Section of the Research and Development Department, for co-operation in experimental work, especially Mr. R. M. Cook, who carried out numerous oxygen determinations.

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A Note on Silicon Distribution between Austenite and Liquid Metal in Freezing Hypo-Eutectic Cast Iron

By A. Hultgren and Olof Carlsson

SYNOPSIS

The silicon distribution between austenite and liquid metal during the freezing of cast iron, as shown in the iron–silicon–carbon equilibrium diagram of Jass, is qualitively confirmed.

Sampling is carried out using a graphite tube, and the assumption is made that no graphite eutectic is formed.

During the freezing of an iron–silicon alloy of suitable composition, the liquid is richer in silicon than is the solid delta iron being precipitated. According to the iron–silicon–carbon equilibrium diagram of Jass,[1] applied to the freezing of cast irons by Hanemann and Schrader,[2] this is true for iron–silicon–carbon alloys up to a certain carbon content, beyond which the tendency for distribution of silicon is reversed. According to this diagram the latter condition is also obtained for ordinary cast iron, in which austenite is the precipitated iron phase. Consequently, while austenite is precipitated and, later, while the graphite eutectic forms, the mother liquor is impoverished in silicon.

EXPERIMENTAL

In view of the importance of the silicon distribution for the interpretation of matrix structures in grey cast iron, a simple experiment was made to confirm the silicon distribution given by Jass's diagram.

A hypo-eutectic cast iron was allowed to freeze

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Professor Hultgren and Mr. Carlsson are at the Royal Institute of Technology, Stockholm.

Table I
CHEMICAL COMPOSITION

Experiment	Sample	Dip	C, %	Si, %	Mn, %	P, %	S, %
1	Main mass		2·60	1·90	0·34	0·28	0·065
	Plug	1		1·81		0·33	
	Plug	2		1·75		0·37	
2	Main mass		2·71	1·93	0·41	0·31	0·080
	Plug	1		1·88		0·35	
	Plug	2		1·71		0·46	

slowly in a graphite crucible. When a suitable mushy stage had been reached, a pre-heated graphite tube, with a small bore and fitting loosely inside the crucible, was pressed down into the melt, causing part of the remaining mother liquor to rise around and into the tube. After freezing, the plug formed in the tube, as well as the main undisturbed mass of metal at the bottom, were analysed for silicon and phosphorus. Figure 1 shows the crucible with the graphite tube and the melt in position before and after lowering the tube.

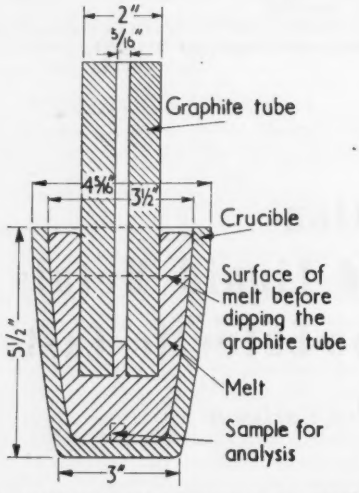

Fig. 1—Crucible with immersed graphite tube

Two similar experiments were made with cast irons of different composition, as given in Table I. In both experiments the melt was heated to 1400° C. in a high-frequency furnace and maintained at this temperature for 5 min. The melt was allowed to cool with the furnace, very slowly, particularly through the freezing range. The graphite tube, heated to dark redness, was dipped twice into the melt, and on removing the tube after the first dip, the portion of the melt round the outside of the tube settled again, but the interior portion had frozen in the hole and remained in the tube. After the second dip, however, the outer portion of the melt remained in its displaced position on removing the tube. The time of each dip was 20–30 sec., and the weight of the plug was about 10 g.

ANALYTICAL RESULTS

The results of the chemical analysis of the plug and of the main mass sampled as indicated in Fig. 1, are given in Table I.

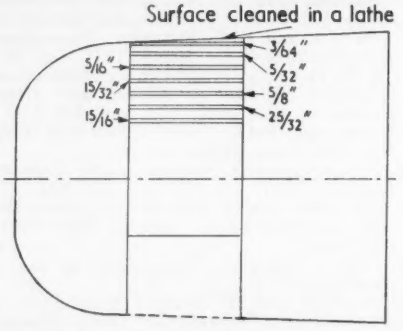

Fig. 2—Position of sampling to ascertain whether segregation occurs

To ascertain whether there was any segregation in the surface layer of the solidified melt a similar melt 3 of cast iron was prepared and allowed to solidify at a similarly slow rate. 1-mm. layers at different depths beneath the surface were removed in a lathe (*see* Fig. 2) and analysed. The following results were obtained:

Depth Beneath Surface, mm.	P, %
1	0·33
4	0·34
8	0·32
12	0·32
16	0·32
20	0·32
24	0·34

From the constancy of the phosphorus figures it may be concluded that segregation is practically absent to a depth of 24 mm. The so-called main mass in Table I, therefore, should have the average composition of the melt; in other words, it represents the liquid metal before freezing.

CONCLUSIONS

It is seen from Table I that, during freezing, the silicon content of the mother liquor is gradually decreasing and the phosphorus content is increasing. In other words the silicon distribution between austenite and liquid metal as shown in Jass's diagram is qualitatively confirmed.

It is assumed that no graphite eutectic had formed, even at the moment of the second dip, but at present this cannot be stated definitely.

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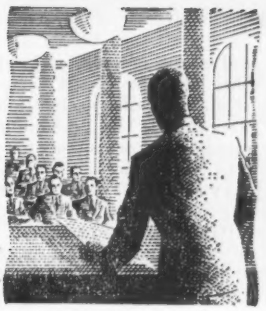
DISCUSSION ON PAPERS



DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

AUTUMN GENERAL MEETING, 1949

The AUTUMN GENERAL MEETING of THE IRON AND STEEL INSTITUTE was held on Thursday and Friday, 10th and 11th November, 1949, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. The President, SIR ANDREW MCCANCE, LL.D., D.Sc., F.R.S., was in the Chair.

The discussion on the papers presented on the first day was published in the November, 1950, issue of the *Journal*.

Discussion on the Paper—

THE COMPRESSION TEST IN RELATION TO COLD ROLLING*

by N. H. Polakowski

In presenting his paper the author drew attention to the following errors in the text :

P. 250, *left, line* 8 *from bottom :* " 10 and 35% " should read " + 10 and − 35% "

P. 252, *right, line* 7 *:* " height. The specimen " should read " height, the specimen "

P. 254, *left, line* 4 *:* " [curve] 2′ " should read " [curve] 1 " ; *line* 7 *:* " curve 2 " should read " curve 1 " ; *line* 8 : " curve 1 " should read " curve 1′ "

P. 259, *Table III :* Analysis of steel 018-a (omitted) should read : " 0·18% C ; 0·64% Mn ; 0·04% Si ; 0·026% S ; 0·009% P."

P. 260, *Fig.* 18, *inscription :* " values) of Cu50-a copper " should read " values). Cu50-a copper "

P. 265, *Fig.* 24, *inscription :*

$$p = \frac{p}{\sqrt{Rb(b + 0{\cdot}000334P)}}$$ should read

$$p = \frac{P}{\sqrt{(Rb(b\delta + 0{\cdot}000334P)}}$$

P. 266, *Fig.* 25, *inscription :* " by Ford[23] " should read " by Ford[15, 23] "

P. 274, *Fig.* 35, *inscription :* For curve *d* the number of pass should read " 4 " (*not* " 7 ").

P. 276, *reference No.* 25 *:* " Lugg " should read " Lueg "

In Tables I and II the values given are in tons/sq. in.

Dr. **L. R. Underwood** (Messrs. W. H. A. Robertson and Co., Ltd.) : This paper is a useful and timely reminder that we may have to revise friction hill theories, especially in regard to the coefficient of friction and the basic yield stress curve.

My only comment on Part I of the paper is that, after reading the author's criticism of the various methods of conducting the compression test, I approached his own method and results somewhat more critically than I might have done otherwise, but my own doubts on this matter have been somewhat allayed by his findings, which do, in a measure, offer what appears to be a possible qualitative explanation of certain phenomena in cold rolling.

My main interest is in Part II of the paper. I was particularly interested in the author's use of the assumption that the coefficient of friction μ between the rolls and the strip is a function of rolling speed, to explain change of strip gauge with speed and allied phenomena. There is, however, little or no real evidence to show that μ does, in fact, vary with rolling speed, and no attempt is made to indicate the magnitude of the change in μ that is necessary to produce the results reported by Ford, and shown in Figs. 26 and 27 of the paper.

It may be of interest, therefore, to refer to some investigations on this subject which I made about three years ago.† Tests had been reported to me in which μ was measured at various rolling speeds by means of both the gripping angle and the forward slip methods, on a two-high strip mill with 30-in. dia. rolls, using aluminium strip with a rolling oil. These tests showed that μ decreased considerably as the rolling speed increased from 50 to about 250 ft./min. External evidence of heat developed in the strip, rolling torque, etc., supported these findings. Since the passes took several minutes to roll, the effects were not transitory.

These observations suggested that a change in μ with rolling speed might be the explanation of the effect of

* *Journal of The Iron and Steel Institute*, 1949, vol. 163, Nov., pp. 250–276.

† Unpublished work.

speed on roll pressure and strip gauge, noted by Ford and others, and also of the variation in gauge found during acceleration and deceleration.

To examine this possibility further, I calculated μ for a number of Ford's tests for rolling speeds ranging from 10 to 300 ft./min., using von Karman's friction hill theory and Cook and Larke's basic yield stress curve for copper, allowance being made for roll flattening by means of Hitchcock's equation. These calculations showed that the change in μ over the speed range of 10 to 300 ft./min., which was necessary to account for the observed changes in rolling pressure in any of the passes, was of the order of 16 to 20%. As this change was relatively small, it seemed quite reasonable to accept it as a possible cause of the observed speed effects.

Mr. Polakowski assumes that, as the rolling speed increases, the coefficient of friction continues to decrease, reaching, at high rolling speeds, very low values. Although this assumption is necessary if the changes in gauge noted by Mohler at speeds of the order of 1600 ft./min. are to be explained by the friction theory, the shape of the rolling-pressure curves in Figs. 26, 27, and 29, and of the curves of μ against rolling speed deduced from them, suggests that, in Ford's tests on the 10-in. Sheffield mill, μ would have become sensibly constant at a speed not greatly in excess of 300 ft./min. The tests on the aluminium cold-rolling mill referred to earlier also suggested that μ would approach a constant quantity at no great speed. Therefore, I think that the author's assumption that μ continues to decrease as the speed increases is open to doubt ; but perhaps he has some further evidence to support his view.

Most of the effects of rolling speed observed by Ford can be explained on the assumption that μ decreases as rolling speed increases, with the exception of the rise in pressure with speed on the first pass or so, which is shown in Figs. 26 and 27. The author's compression curves, however, now offer a qualitative explanation of this phenomenon, and it would be interesting to know whether they also offer a satisfactory quantitative explanation.

My calculations on the relationship between μ and rolling speed also showed that, while the change in μ from 10 to 300 ft./min. for a series of successive passes, such as those shown in Fig. 27, was of the same order for all passes, the average value of μ decreased as the number of passes from the annealed state increased. Thus, referring to Fig. 27, for the 4th pass I found that μ ranged from 0·12 at 7 ft./min. to 0·1 at 300 ft./min. In the 6th pass the corresponding figures were 0·095 and 0·08, and in the 7th pass 0·084 and 0·065. To put these figures in another way, at 300 ft./min. the value of μ had decreased from 0·1 in the 4th pass to 0·065 in the 7th pass. So far as I can see, this result is not explained by the author's compression-test results, nor do I think that it is caused by errors in Hitchcock's equation for roll flattening. It could, however, be explained if μ was a function of roll pressure as well as of rolling speed. Further calculations of μ for rolling tests on copper, in which the rolling speed was constant, support this view, and suggest that μ decreases as the rolling pressure increases. Has the author considered this possibility ?

The author refers to change in μ with speed, and I presume that he means rolling speed. In my own work, I thought it better to base my calculations and curves on the relative slip between the roll and the strip, as this speed, and not the strip speed, will govern the change in friction. This can be readily seen when it is realized that, with a constant strip speed, slip speeds between the roll and the strip can be varied over a wide range merely by altering the percentage reduction.

The rate of slip between the roll and the strip varies throughout the arc of contact, being a maximum at entry, zero at the neutral plane, and a small value at exit. If, then, μ is a function of speed, it is logical to assume that μ will vary from point to point along the arc of contact, rising from the plane of entry to the neutral plane, and then decreasing. The pressure also varies in the arc of contact, reaching a peak at the neutral plane. Hence, if the view that μ is also a function of roll pressure is accepted, μ will, owing to pressure, decrease from the plane of entry to the neutral plane, and increase again towards the plane of exit. The actual operative value of the coefficient of friction in the arc of contact will, therefore, be the result of combining the variations caused by speed with those caused by pressure.

If these statements are valid—*i.e.*, if μ varies with both the roll pressure and the slip speed from point to point along the contact arc—the classical friction hill theories of roll pressure, based on a constant value of μ, will have to be amended. The characteristic sharp peak will probably be replaced by a rounded peak, and some of the present discrepancies found between the calculated and measured values of roll load will, possibly, be explained. The mathematical difficulties introduced would, of course, be tremendous.

If the author continues his work on friction in rolling, I think that he may find, as I have, that the assumption that μ is a function of speed is not always by itself an adequate explanation of phenomena associated with rolling speeds.

Dr. **H. Ford** (Imperial College of Science and Technology) : The comparative yield stress values for copper set out in Table I are rather misleading without some explanation of the way in which the yield stress curves were determined. My own yield stress curves in plane compression effectively prevent spread in the lateral direction, and, therefore, the yield stress will be higher than that determined in the other tests, where a definite attempt was made to realize homogeneous compression, *i.e.*, lateral extension equally in all directions. This applies, to a lesser extent, to the results of my tensile tests, since deformation was caused by rolling. There is no direct comparison possible, therefore, without some recourse to theory, in which the nature and extent of the deformation can be taken into account.

The author's criticisms of the Cook and Larke method are not, in my opinion, justified, because their method does attempt to remove the effect of friction, whereas the author's test makes use of the friction between the end platens and the specimen. Cook and Larke used specimens of a material all having the same diameter but different heights. They carried out compression tests, noting the vertical deformation and the load causing that deformation. Yield stress curves were plotted against the ratio d/h, and by extrapolating to zero the value of the ratio d/h, the yield stress at various reductions was obtained as the intercept on the ordinate. They argued that the effects of friction at the ends of the specimen would become smaller as the specimen became longer. This means that the friction ' cones ' at the ends of the specimen occupy a decreasing fraction of the total length, and the frictional enhancement of the yield stress decreases, becoming zero at infinite height, *i.e.*, at zero d/h.

The author says that in this test true barrelling will be obtained at the ends. From a large number of tests that we have made there is no indication whatever that this is so. Even if it were so, wherever the extrapolation can be reliably carried out, the frictional contribution will be reduced to negligible proportions. St. Venants' principle applies equally in plasticity as in

elasticity : the actual shape and form of the end regions are of no importance when the height becomes large compared with the diameter. My experience has been that the extrapolation becomes difficult and may be unreliable in the Cook and Larke method when the percentage reduction in height is more than 50–60%, and an alternative procedure becomes necessary for heavy deformations ; but the Cook and Larke method is sound within the lower range.

I regret that the author has not given rather more details of his experimental method, to allow a better assessment of the value of his technique. In my view it is not possible to machine specimens without causing some hardening of the specimen itself, and, particularly after repeated machining, the modifying effect will be fairly important.

A more serious disadvantage is the effect of machining in modifying the distribution of work-hardening over the specimen. In Fig. 14, the author shows some hardness distributions determined by Siebel ; before machining, the deformed specimen has developed a distribution of hardness by non-uniform deformation, which will bring it into equilibrium with the external force system. If, now, the outside layers are removed, as shown in Fig. 14, a different stress distribution results the moment the load is applied, and further non-uniform deformation is obtained. I am not entirely satisfied that balancing the change in hardness—in other words, the differences in yield stress—throughout the specimen against the friction at the ends (p. 258) is really a criterion of homogeneous compression.

I consider, therefore, that to base the yield stress curves on tests where the amount and nature of the deformation is not taken into account is open to question. At the Imperial College we have made some progress in relating to each other yield-stress curves obtained with different modes of deformation (*e.g.*, plane compression, the homogeneous compression of Cook and Larke, incremental loading, etc.) by assessing the true amount of deformation. The work is continuing and will be reported later.

In Fig. 12 the author shows some sections of a specimen which has been compressed, and he indicates that fibres in the specimen can be treated as struts loaded by the end pressure. The stress distribution is much more complicated than this, and, before drawing conclusions, it would be necessary to demonstrate that the circumferential stresses and the presence of material inside the annulus had a negligible influence on the stress distribution.

Referring to Fig. 16, I should like the author to define the " transverse stress T." Is this a circumferential stress distribution, an end stress distribution, or a radial distribution ?

The author refers to the test for compression in plane strain described in my paper on cold rolling* and states that a tool length-to-width ratio of 10/1 is too small to ensure plane strain. A little consideration will show that the factor causing plane strain is not the friction between the tool and the material, but the effect of the unstressed material at each side. The total frictional effect in the length direction is not as great as in the width direction, but the main factor affecting spread is the material beyond the tool. We have proved that this is so by carrying out tests with specimens which are narrower than the tool width, and also with specimens which are wider than the tools, where there is unstressed material beyond the platens constraining the actual material between the platens. In the first case, the spread is fairly large, but in the second case, the spread is found to be negligible, so that the yield stress curves given by the test do represent plane-strain compression to a close approximation.

On p. 257 the author says that he believes that between 75 and 80% " is the upper limit of applicability of this rapid and simple method." The limit depends entirely upon the size of the tool and the initial thickness of the material. If the test is made with a slab, which is initially fairly thick, and with narrow tools, reductions of up to 96 or 97% can be made without excessive friction invalidating the results.

The author's suggestions in Part II of the paper are interesting, although I doubt whether the friction between the roll and the material can vary sufficiently to account for the change in roll force with speed found in the tests referred to. For instance, from the set of curves in Fig. 26 or Fig. 27, though I know that the author has attempted an explanation of this, it would seem that the friction has to change in two directions with speed, because where the material is thick the roll force increases slightly, and where the material is thin the roll force decreases. The data given in Table IV, taken from my paper,† refute the author's explanation of the speed effect as a friction effect, and his suggestion that, in this particular experiment, the surface layer was melted by the friction work cannot be accepted. The conditions in this test were no different from those in the other tests, and the same explanation must fit all the results.

It is a little unfortunate that Figs. 27 and 31 have been taken out of their context in the original paper. These figures show ' peaks ' in the curve of roll pressure against speed. An explanation of the peaks was given in the original paper. It was found that they were caused by slight differences in the initial and final thickness of the strip, and it was shown that it was possible to obtain a smooth curve by taking greater care in adjusting the screw-down gear. I do not think that there is any other significance in the peaks.

Mr. **J. Gibson** (Cambridge University) : It will be seen from Table I that the compression curve for copper obtained by the author and that obtained by Taylor and Quinney‡ are very similar up to about 60% deformation, the author's values being about 2% greater. Beyond this point Taylor and Quinney's curve flattens out to a value of 26·1 tons/sq. in. for 90% strain, whereas the author's becomes steeper, rising to 30·9 tons/sq. in. for the same strain.

In their test, Taylor and Quinney applied the load in small increments and removed the specimen after each loading to re-grease the faces. In addition, the diameter was machined down after each 40% reduction. By this method the effect of friction was almost eliminated and barrelling was very slight. The author himself describes this method as " apparently reliable," and yet makes no comment on the considerably different result it produces. Figures 17 to 19 show that, for strains above about 60%, the curves for tests with end friction rise above those for tests using smooth lubricated tools, and the curves in Fig. 9 show that the flatter the specimen the greater this rise is likely to be. Thus it is all the more striking that Taylor and Quinney's curve remains flat at very large strains when the h/d ratio is of the order of 0·05, and it appears that in this test friction really is negligible,

* H. Ford, *Proceedings of the Institution of Mechanical Engineers*, 1948, vol. 159, p. 115.

† H. Ford, *Journal of The Iron and Steel Institute*, 1947, vol. 156, p. 380.

‡ G. I. Taylor and H. Quinney, *Proceedings of the Royal Society*, 1934, Series A, vol. 143, p. 307.

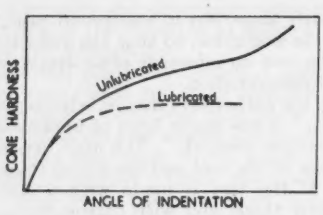


Fig. A—Influence of lubrication in the cone indentation test

resulting in a very close approach to pure uni-axial compression. It is surprising that the author, using comparatively slender specimens, should obtain a higher curve. If one of the main objects of this investigation is to produce a compression curve which is reliable up to such large strains as 90%, some satisfactory explanation of this discrepancy must be found.

Professor **H. O'Neill** (University College, Swansea) : Part I of the paper is the crux of the whole thing, so far as I am concerned. I preserve an open mind about the justification of the relative position on the stress axis of the stress/compression curves obtained with " no friction " and in the ordinary way. Dr. Ford has ably stated the criticisms that might be made against these curves which the author obtains that are above those obtained in the simple compression test. I intended to raise the same criticism, because we are not clear in Swansea about the explanation of the results. After the first stage of compression, according to Siebel's hardness contours, the metal is a little stiffer inside, and when the outer layer is machined off and the metal is compressed it may be a little harder than the average before machining. This might account for the author's basic curve being at a little higher stress. However, the hardness gradient is very small, and only of the order of 4%, according to Siebel's figures, whereas the displacement of the author's curve over the ordinary curve is more than that. Furthermore, the machining of the surface removes some of the harder skin around the soft cones at the top and bottom of the specimen, and this has a compensating effect.

There is also the question of internal stress in the initially compressed specimen. When this is machined there is a redistribution of the internal stresses. Whether that would react to produce a higher average yielding stress at the next stage I do not know. The author has put forward some stress adjustment ideas in the paper, but I do not think that he considers that they are final.

Those who object to the author's method have similarly, I think, to object to determinations of the tensile strength of progressively cold-worked metal where a tensile test piece is machined out of the cold-rolled stock.

Another reason why I have an open mind about the relative positions of the diagrams is that in indentation tests (where friction is involved) there is a displacement of the hardness curves in the lubricated and unlubricated condition, and the work of Kuntze* suggests that the curves are moved in the opposite direction to that mentioned by the author. If cone hardness, which is stress, is plotted against some function of deformation (which is cone angle in Kuntze's work), the curve obtained is of the type shown by the full line in Fig. A, and is not unlike the author's. But if the loading of the cones is done in stages and lubrication is applied—*i.e.*, if an attempt is made to obtain a cone indentation test where the friction is eliminated—the curve is lower, as shown by the dotted line. That is contrary to the author's idea, but I think that it can be explained on other grounds, for the cone indentation test is not necessarily directly comparable in this respect to the compression test.

The main point is that when the author applies what he calls his true curve to a study of cold-rolling operations he believes that he can explain some of the anomalies of the latter. Dr. Underwood seems to support him in this view, and so I think that the author has done a very useful piece of work.

Mr. **W. C. F. Hessenberg** (British Iron and Steel Research Association) : Figure 18 illustrates the most striking point that the work done in compressing the specimen with rough tools is less for certain reductions than with smooth lubricated tools. Dr. Ford and Mr. Gibson have already hinted at an explanation of this, but I am not sure whether it is the same as my own, and I will put it in a slightly different way. Cook and Larke† showed some micrographic sections of pieces that had bowed edges when compressed with rough tools, but there was very little bowing when smooth tools were used. In the first piece there was evidence of non-plastic wedges, while the other specimen was deformed all over the section. If a piece is machined from both, the ratio of unworked to worked material is increased in the first specimen and not in the second, and therefore, as the process went on, it might be expected that the former would be slightly softer on recompressing than the latter. I think that is why the curve lies below in Fig. 18 when rough tools are used.

If the yield stress is properly defined, then these conflicting views of what the yield stress really is, in different methods of compression, tend to disappear. I should define the yield stress as follows : If W is the work of compressing unit volume of the material, then the yield stress is simply given by the integral of $Y(\varepsilon)d\varepsilon$, where ε is the strain and Y is a function of the strain. To find Y the strain must first be determined, and I suggest to the author that he should make compression tests on specimens either of multi-coloured plasticine or of metals with grids drawn on them, and estimate the actual strain which he gets, at the same time noting how much 'strain' he turns off by his machining process.

Mr. **M. F. Dowding** (Davy and United Engineering Co., Ltd.) : The value of the rolling load and rolling torque is fundamental to a mill designer. To design a new mill it is essential to have a reliable method of assessing this rolling load and torque for the programme which the mill is required to roll. So long as our calculated values are well on the high side it is not necessary to go to the accuracies which this paper suggests, for we must put forward a mill of ample weight and power, knowing that after a few years' use the specified programme may have been exceeded and a more onerous duty demanded from the mill.

Our normal practice is to compile these rolling loads and torques on the assumption that the friction hill theory, detailed by Orowan and Ford and the present B.I.S.R.A. team in Sheffield, is correct. In fact, within the limits of industrial cold rolling, between, say 0·10-in hot-finished steels, and 0·01 in., or slightly below, for the average gauge of tinplate, results have proved to

* *See* H. O'Neill : " Hardness of Metals and its Measurement," p. 37, Fig. 5, London, 1934. Chapman and Hall.

† M. Cook and E. Larke, *Journal of the Institute of Metals*, 1945, vol. 71, p. 371.

be sufficiently accurate. This paper throws some doubt on the accuracy of these theories, which I should like to see dispelled.

My company has recently been carrying out tests on production mills to see what rolling torques are used when they are actually rolling normal industrial production programmes. Our early results—it is too soon to give them more value than that—and the results recently put forward by the experimental mill team at Sheffield under Mr. Sims, have shown that the agreement between experimental results and these theories is close enough for our purposes.

I should like to know whether the author will be able to present the results in such a way that we shall be provided with a quick and accurate method of calculating the rolling load and rolling torque required for a given reduction on normal industrial metals.

Mr. **A. B. Watts** (Imperial College of Science and Technology) : In regard to a remark made by a previous speaker, I do not consider that the residual stresses after rolling are appreciable. When the material is in the roll gap it is in the plastic state, which extends right across the material, unless it is particularly thick. I think that the effect of anisotropy, developed during rolling, is far more important than residual stresses.

The author, in making a compression test, allows himself 25% reduction on his initial annealed cylinder, and claims that the variation in the yield stress, which he measures by hardness, is then very small. My point is that the value of the coefficient of friction is not constant throughout the compression ; it depends upon the way in which the actual surface of the specimen is deformed. It is my experience that the nature of the surface above, say, 40% reduction in height in the compression test, actually changes to take up any grinding or polishing marks left on the platens against which it is being compressed, and a 25% reduction made at a total reduction of, say, 60% leads to greater inhomogeneity than that caused by the 25% reduction made on the annealed specimen.

My second point is in connection with the test which Dr. Ford instituted when he was carrying out his rolling research. The author mentions that for thick stock—*i.e.*, 0·1 in.—with a 2-mm. tool, the yield stress is considerably above what might be expected. He explains that he believes that this effect is caused by friction, but I do not think that we can hastily assume this, because the frictional effect should increase as the material becomes thinner and the yield stress rises. In fact, initially the apparent is higher than the true yield stress, because the tool breadth is less than the thickness of the material. Dr. Hill mentions this in the discussion on Dr. Ford's paper,* and explains why the stress that he measured was higher than the actual yield stress. The ratio used by Dr. Ford with the 0·1-in. material was between the ideal 1 : 1 ratio and the peening condition which is reached when the thickness of the material is $8\frac{1}{4}$ times the breadth of the tools.

I also disagree with the view that Dr. Ford's method fails at 80% reduction. It is entirely a matter of whether the tool breadth bears the correct relationship to the material thickness at that instant. If the test is continued to 80% reduction and friction throws the curve upwards, there is no reason why narrower tools should not be used to restore the 1 : 1 ratio.

It is my experience with the Taylor and Quinney test that the re-greasing of the specimen during the compression test, where it is removed after small decrements of, say, 2%, is less important than the removal of the load and the movement of the specimen itself on the platens. Using a method where the specimen is not removed from the tools, but is merely moved a finite amount, I have determined curves very close to the homogeneous compression curve. I have extended the method as far as about 55% reduction, and the barrelling is almost entirely eliminated. The curve is the same as the curve obtained from the Cook and Larke extrapolation, both with highly polished platens and with rough-turned platens. These curves are shown in Fig. B. The incremental method is mentioned in a communication on a paper by Dr. Voce,† which Dr. Ford and I sent to the Institute of Metals.

On the bottom curve (Incremental loading *a*), proceeding as far as 55% reduction, the compression was made in stages as small as possible (½–1%), using mineral oil as a lubricant. This curve should lie below the others, since a removal and reapplication of the load produces a hysteresis curve that turns before it reaches the yield envelope.

For the other curve (Incremental loading *b*) the compression was made in 2–3% reductions, again with mineral oil as lubricant. The curve agrees closely (within 0·5–1%) with the points on curves obtained with the method of Cook and Larke, one with rough platens and one with polished ones.

I believe that the elimination of barrelling by this incremental method gives true homogeneous compression. Furthermore, extrapolation from rough platens agrees closely with that from smooth.

* H. Ford, *Proceedings of the Institution of Mechanical Engineers*, 1948, vol. 159, p. 157.

† E. Voce, *Journal of the Institute of Metals*, 1948, vol. 74, p. 766.

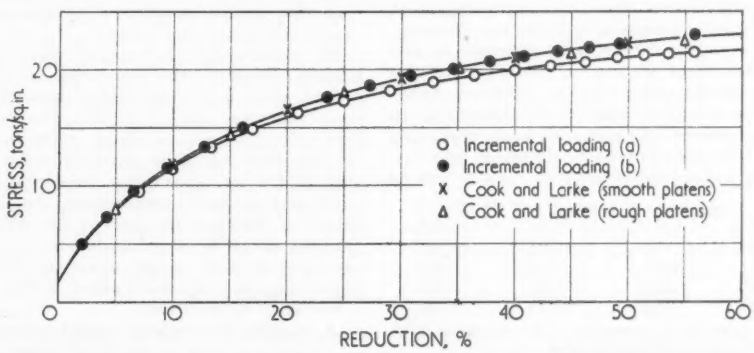


Fig B—Yield stress curves for H.C. copper of commercial purity, 1-in. stock

Dr. **C. H. Desch,** F.R.S. (Past-President) : Have any experiments of this kind been made while the specimen is kept under uniform, very high hydrostatic pressure, as in the experiments on rocks, which were made in America and gave very interesting results ? Bridgman used extremely high hydrostatic pressures, and was actually able to deform a cylinder of granite without cracking.

Although the name of Ludwik appears in the references, there is no reference made to the original memoir by that author, in which he achieved remarkable agreement between tensile and compression curves.

CORRESPONDENCE

Mr. **J. S. Caswell** (University College, Swansea) wrote : An element of material near a platen face is subjected to axial intrinsic yield stresses σ_a and complementary shear stresses $\mu\sigma_a$, consequent on the effects of platen friction. It is also subjected to radial compressive stresses and circumferential tensile stresses, consequent on the flow directions during deformation. The combined effect of the circumferential tensile stresses and the radial compressive stresses may be considered equivalent to the effect of opposed radial compressive stresses, σ_r. The idea, expressed by the author, of a purely hydrostatic condition of stress distribution is scarcely tenable. An analysis of the conditions defined leads to the following expressions relating to : (*a*) the value of the major principal compressive stress σ_p. (This is the stress necessary to overcome both the intrinsic resistance to deformation σ_a and the effects of platen friction) ; and (*b*) the base angle, α, of the cones enclosing the zones affected by platen friction :

$$\sigma_p = \frac{\sigma_a + \sigma_r}{2} + \left[\frac{(\sigma_a + \sigma_r)^2}{4} - (\sigma_a\sigma_r - \mu^2\sigma_a^2)\right]^{\frac{1}{2}}$$

$$\alpha = \tfrac{1}{2}\tan^{-1}\frac{2\mu\sigma_a}{\sigma_a + \sigma_r}$$

Because of the direction of flow under compression, it can be expected that the stress σ_r will be less than σ_a, but approach to equality occurs with decrease in the value of the coefficient of friction μ. To examine the effects of changes in the value of μ, an arbitrary value of $\sigma_r = 0{\cdot}75\sigma_a$ was assumed, and it is interesting to observe how the values of σ_p/σ_a, α, h_0/d_0 and d_0/h_0 change, and also how they appear to represent approximately what might be expected. The results are as follows :

μ	σ_p/σ_a	α	h_0/d_0*	d_0/h_0*
0·10	1·03	19½°	0·35	2·85
0·20	1·11	29°	0·55	1·82
0·30	1·20	33½°	0·66	1·52
0·40	1·30	36½°	0·74	1·35

* The values of h_0/d_0 and d_0/h_0 correspond to the dimensions of the specimens when the apices of the conical zones meet.

Several conclusions are suggested by these results, and they are in accord with some of the observations and statements made by the author :

(*a*) The greater value of the principal compressive stress in the conical zones implies that preferred deformation will take place outside these zones.

(*b*) Initially, therefore, there is an undeformed zone which tends to remain undeformed as compression proceeds ; it becomes bounded on the conical surfaces by the build-up of material with increasing degrees of work-hardening, thus producing conical zones of gradually increasing height, as shown in Fig. C.

(*c*) The progressive entry of material within the zone affected by platen friction, and the cumulative work-hardening which occurs, indicate that the magnitude of platen friction determines the location of lines of equal and increasing hardness on a diametral plane of the specimen. It appears that hardness would increase most rapidly perpendicular to the conical surface.

(*d*) Contrary to Riedel's suggestion discussed on p. 263, that the semi-cone angle reaches a value of 37½°, *i.e.*, a corresponding base angle of 52½°, it seems unlikely that the base angle could exceed 45°. The author suspects error because his own conclusions, supported by those of Meyer and Nehl, show that the rise of the yield stress was apparent when $h_0/d_0 = 0{\cdot}75$ or $d_0/h_0 = 1{\cdot}33$. The rise is attributed to the meeting of the apices of the cones, and it is of interest to observe in the results already given, that, for a value of $\mu = 0{\cdot}4$, the value of the d_0/h_0 ratio, when the cone apices meet, is 1·35, which agrees closely with what was found experimentally by the author, corresponding to a base angle $\alpha = 36\frac{1}{4}°$ or a semi-cone angle $\phi = 53\frac{3}{4}°$.

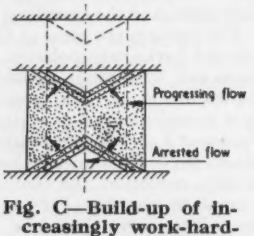
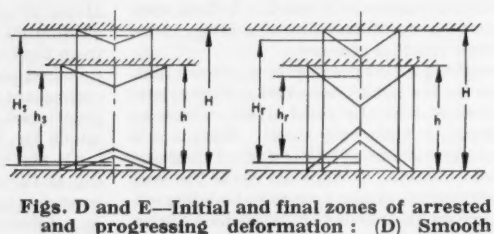


Fig. C—Build-up of increasingly work-hardened metal. Arrows show directions of increasing hardness



Figs. D and E—Initial and final zones of arrested and progressing deformation : (D) Smooth platens (low μ) ; (E) rough platens (high μ)

(*e*) When the friction-affected zones coalesce, the plastic stress enters into what might be termed a second order, in which the stress required to produce deformation is governed by the preponderating effect of the conditions of contact between the specimen and the deforming tools.

Mr. Polakowski's conclusion, that an increase in end friction decreases the resistance to deformation, is in accord with a corresponding deduction made by me some years ago, *viz.*, " the slip which occurs on the roll face will give rise to a higher stress value in the zone of no slip than would be required under conditions of no slip."* For two specimens, similar in detail and dimensions and similarly compressed, the difference in resistance to deformation, except for differences in platen friction, must be attributable to the difference in the amount of work done, since the change of height—neglecting the very small effect of the elastic recovery—is the same in each case.

A simple theoretical consideration of this matter

* J. S. Caswell, " The Engineer," 1930, vol. 149, p. 289.

follows, and it is sufficient to assume perfect plasticity, because the argument remains valid for any condition of work-hardening, provided that this condition applies to the two cases considered. It is assumed that a specimen is deformed a given amount under conditions of either low or high platen friction, which is assumed to have correspondingly low or high coefficients of constant value. The specimen and the effect of the platen friction on the conical zones are shown in Figs. *D* and *E*, which illustrate the alternative conditions.

The pure deformation work outside the influence of the platen friction may be approximately represented by the following:

$$\sigma_a A H_S . \ln \frac{H_S}{h_S} \text{ for smooth platens } *$$

$$\sigma_a A H_R . \ln \frac{H_R}{h_R} \text{ for rough platens}$$

where σ_a = constant plastic stress, *i.e.*, load per unit area

A = initial cross-sectional area

H_S, h_S / H_R, h_R = the original and final heights in each case of the equivalent cylindrical volumes undergoing pure deformation unaffected by platen friction.

In addition to the work of pure deformation, there is, in each case, work of a confused kind, taken up in the deformation of material near the platen faces, and also in overcoming frictional resistance where sliding takes place over the platen faces. This additional work may be represented by W_S for the smooth case and by W_R for the rough case. The total work for a given change of height, H to h, in each case is then approximately:

$$\sigma_a A H_S . \ln H_S/h_S + W_S \text{ for smooth platens}$$

$$\text{and } \sigma_a A H_R . \ln H_R/h_R + W_R \text{ for rough platens}$$

Since the change of height H to h is the same in each case, and the volume is assumed to remain constant, the author's theory requires that the average resistance to deformation for the smooth platens shall be greater than for the rough platens. The manner of the deformation and the influence of the platen friction also indicate that the difference between the respective average values would at first be very small, and afterwards become more and more marked in the later stages of deformation, because of the more rapid growth of the conical zone in the case of the rough platens. To verify the author's theory, it is necessary to show that:

$$\sigma_a A H_S . \ln H_S/h_S + W_S > \sigma_a A H_R . \ln H_R/h_R + W_R, \textit{ i.e.},$$

$$\frac{1}{\sigma_2 A H_R}(W_S - W_R) > \ln H_R/h_R - \ln H_S/h_S, \text{ since } H_S > H_R$$

$$\text{or } (W_S - W_R) > \sigma_2 A H_R \ln \left[\frac{H_R/h_R}{H_S/h_S}\right] > \ln \left[\frac{H_R/h_R}{H_S/h_S}\right]$$

This would indicate that $W_S > W_R$ if the right-hand term is positive. It may be shown both by deduction and observation of the diagrams that $(H_R/h_R)/(H_S/h_S) > 1$, thus making the right-hand side positive, and therefore that $W_S > W_R$. Since the work of pure deformation $\sigma_a A H_S . \ln(H_S/h_S)$ is greater than $\sigma_a A H_R . \ln H_R/h_R$ it appears that the author's theory is correct. Under the hypothetical condition when the coefficient of friction $\mu = 0$, the total work of deformation must necessarily be greater than that required in the case of the rough platens. The foregoing comparison applies as long as the conical zones remain apart. When these zones meet and coalesce, plastic flow of a second order occurs, as already suggested under (*e*) of the observations on p. 310. For such conditions a new analysis is required.

I have assumed simplified contact conditions, but it is apparent that these conditions are not simple, and under conditions of high-speed rolling they become very complex. They are related to the phenomena associated with the diminution of friction between high-pressure contact surfaces due to lubrication. Bowden and Tabor† defined normal metal surfaces as consisting of: (*a*) surface irregularities; (*b*) an oxide film; and (*c*) an altered layer in the metal itself. When the lubricating film breaks down, metal to metal contact occurs, and, at the isolated points of contact, local adhesion and pressure welding take place. Frictional resistance is then primarily caused by the shearing of these metallic junctions.

It is probable that these conditions exist at the contact surfaces in compression tests under static and live conditions. In the case of high-speed rolling, local heating accompanying the rapid rate of work may increase the mobility of the metallic surface film, and so make it an additional factor related to some of the puzzling phenomena observed in rolling practice. Further research should include investigation of the effects of defined surface conditions, such as are now possible with the sensitive methods available.

Mr. **A. W. Brace** (The Aluminium Development Association) wrote: There are several points on which the author's experimental methods seem open to question. Firstly, a constant h/d ratio has been maintained throughout the test. It seems doubtful whether this is the most appropriate ratio to ensure that compression conditions may be the same throughout the test. A constant h/a ratio would appear to be more appropriate.

With a $\frac{3}{4}$-in. dia. specimen the height would be approximately 1·7 in., the h/d ratio would be 2·2, and the h/a ratio 3·9. After 50% compression the height would be 0·85 in. and the re-machined specimen would have a diameter of 0·49 in. Although the h/d ratio is 2·2, the h/a ratio is 0·85/0·31, *i.e.*, 2·8. Since the values for the deformation of geometrically similar specimens are normally identical, the constant h/d ratio would give rise to errors at the higher deformation values, owing to tendencies to buckling or barrelling because of the changed h/a ratio.

The general features of the compression curve are well known. The characteristics of specimens deformed with rough and smooth tools is of importance in fields other than rolling; thus, in rivet practice the metal may be compressed to give a 60% increase in diameter to form a head. It would be useful to know if the formula $V = Td^2/(4)h$ could be applied to Figs. 11–21, in order to re-draw the curves on the basis of load *versus* increase in diameter.

In dealing with aluminium alloys there is a sharp increase in the load required for a 60% increase in diameter in compression over that required for a 50% increase. Any means of reducing the difference between the two values might be useful where working operations require deformation of this order.

Finally, does the author consider that the position of the critical point on the compression curves for rough and lubricated specimens could be changed by varying the lubricant or smoothness of surface?

AUTHOR'S REPLY

Mr. **N. H. Polakowski** wrote in reply: Dr. Underwood's report of the tests carried out on the aluminium strip mill, which indicated that μ decreased when the rolling speed was raised, is very interesting. That the heat developed in the strip, the torque, and the gripping angle were all less at the higher speeds is particularly noteworthy. The estimation of μ from the value of the

* ln = $\log_e$.

† Annual Report, Chemical Society, 1945.

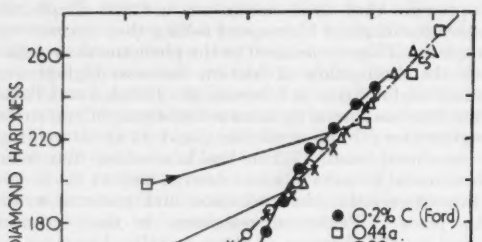


Fig. F—Relation between compressive yield stress and hardness

forward slip alone may be uncertain, as the latter sometimes behaves contrary to what would be expected in theory. I did not try to connect the results of Pomp and Lueg[1] and Lueg and Schultze[2] with my own conclusions because I expected more comprehensive results to be published by B.I.S.R.A.

The results of Dr. Underwood's computations of μ for varying speed conditions agree with those obtained by myself. By using Ford and Bland's formula,[5] I have found that a decrease of μ from about 0·085 to 0·065 is sufficient to account for a 45 to 50% drop of roll force when rolling thin and hard copper strip with alternatively low and high speeds.[4]

I agree that μ should have been related to the relative slipping velocity rather than the roll speed, but this was without practical significance in the rolling tests considered in the paper. With a constant roll diameter (10 in.) and an identical initial strip size, there was a simple relation between the roll speed and the relative speed of the roll and the stock.

In reply to Dr. Ford, my remarks at the foot of p. 265 were formulated primarily with the object of drawing attention to the non-interchangeability of yield values obtained with the three different methods : (i) Dr. Ford's plane compression test ; (ii) 1·15 × tensile stress ; or (iii) 1·15 × free compression stress. That this is so can be seen if it is considered that, contrary to what might be expected, the initial yield stress value is equal in (i) and in simple tension, as shown in Fig. 16 of Dr. Ford's paper.[5] The difference between both curves is being developed gradually, reaching a maximum somewhere between 20 and 30% reduction, and slightly decreasing still later. The comparison would be better if a curve for free axial compression were available for the same steel. It is shown in Fig. F that, qualitatively, the same relationship seems to hold when Vickers hardness is plotted versus compressive stress. There is no general relationship between hardness and yield stress at the early stages of compression, but after approximately 10% deformation, each individual curve joins the straight line *S–V*, without regard to initial properties and composition. When Dr. Ford's stress/hardness values are plotted on the same diagram, it can be seen that, for the same degree of work-hardening, as determined by Vickers hardness, his 0·2% carbon steel exhibits a much higher resistance to deformation than cylindrical specimens, where spread is unhindered. Yet, at the higher compression stages, this particular curve also comes to the common *S–V* line, thus suggesting that, in this range, the lateral constraint ceases to play any appreciable rôle, and that the factor 1·15 converges towards unity.

It is quite clear that the slope of the curves *a–h* (Fig. 10) in Cook and Larke's method can be varied, within fairly wide limits, by using different combinations of specimens (d_0/h_0) and platen finish. Rough plates will artificially exaggerate the slope, and will result in a lower extrapolated yield value (*i.e.*, intercept) as compared with smooth plates. Finally, if Sachs' original concept, on which Cook and Larke's method is based, were to be followed strictly, the stress would have to be calculated from the maximum cross-sectional area at the barrel, which is always greater when end friction is high. Consequently, the resulting compressive stress would be still less than that shown in Cook and Larke's diagrams, and much less than is obtained with smooth plates.

Machining was carried out with a dead-sharp tool, and cooling was used when required. I was unable to detect any surface hardening effects. The possible effects of repeated machining are not cumulative, as each consecutive operation removes all traces of the previous one. The results of Figs. 17–19 were obtained without interstage machining.

The hardness distribution, shown in Fig. 14, is appropriate for a single-step compression with high end friction. The actual differences in hardness after 25% incremental compression are insignificant, and, even at 70 or 75% deformation, the variation of hardness over a vertical cross-section rarely exceeds 5%.

In answer to Mr. Dowding, I aimed, in my experiments, to provide a rational explanation for some practical aspects of strip rolling which are of interest to users of mills, and which could not always be satisfactorily explained by mill builders alone, *e.g.*, the speed effects. I did not contest the accuracy and reliability of the B.I.S.R.A. results, on which, in fact, a good deal of the paper was based. However, I doubt whether much success will be achieved by trying to estimate, with the formulae quoted by Mr. Dowding, the roll separating force in the last two stands of a 4-high tandem tinplate mill with 20–22-in. work rolls. If the delivery thickness is about 0·02 in. or less, and assuming that $\mu = 0{\cdot}05$, *i.e.*, a very low value (*see* Reference 5, pp. 134 and 140), with normal drafts and tensions, the calculated roll force will exceed the measured one by approximately 50%, or even more.

FURTHER AUTHOR'S REPLY

Mr. **Polakowski** wrote in a further reply : Dr. Underwood's suggestion that μ should depend not only upon speed but also upon pressure is supported by the experiments of Dokos,[6] but it appears that speed is the more potent factor affecting friction.

The reason why the roll load became sensibly constant at speeds as low as 250–300 ft./min. in Dr. Underwood's and Dr. Ford's tests, was, in my opinion, firstly the softness of the material, and secondly the relatively small roll diameter of 10 in. It can be shown theoretically that variation of strip gauge is likely to be much greater in 4-high mills than 2-high. A 5% change of μ will obviously have little effect on strip thickness in a 2-high mill with 10-in. rolls when rolling 0·010-in. mild-steel strip. However, it will cause a considerable difference in a 4-high tinplate mill with 20/45-in. rolls, where the effect is, in addition, cumulative in the last three stands, although the simultaneous changes of roll load can only be negligible. A 5-stand tinplate mill comes ' on gauge ' between 1000 and 1500 ft./min., the operating speed being 3300 ft./min.,[14] and, during deceleration,

the correct gauge can be held down to between 700 and 800 ft./min. The variations of strip thickness, noted by Mohler at the higher speeds, were small, and they became excessive only when the mill was substantially decelerated (from 1600 to between 600 and 800 ft./min.). It appears, therefore, that a steady value of μ is reached at speeds higher than 300 ft./min.

Dr. Ford considers that the Cook and Larke extrapolation is correct and its physical basis sound, since the 'friction cones' at the ends of compressed cylinders occupy a decreasing fraction of the total volume when the height increases continuously but the diameter remains the same. I cannot agree with him, for the following reasons.

The reasoning of Sachs, Cook, and Larke, and of Dr. Ford himself, is based upon the possible analogy between the behaviour of comparatively short ($h_0/d_0 < 3$) and very tall cylinders (say, $h_0/d_0 > 5$). A cylinder with $h_0/d_0 = 2{\cdot}5$ (*see* *A*, Fig. G), after approximately 40% compression, will acquire a form *B*, and it would be expected that, on compression of a cylinder with $h_0/d_0 = 6{\cdot}4$ (*C*) by applying the same load as formerly the contour *D* would be obtained. Because of the identical dimensions of the slip cones *S* in both *B* and *D*, the curvature of the portions near the ends in *D* would be the same as in *B*. It is obviously unlikely that the portions of the generator of the compressed cylinder remote from the plates should be continuously convex towards the outside, because the action of the slip cones cannot reach very far: hence the tacit assumption that the central main part of a long cylinder remains cylindrical after compression, as is indicated in *D*. In this case the cross-sectional area of the cylindrical portion p_1 must be approximately equal to that at the mid-height of specimen *B*, and this is the logical reason why Sachs recommended the latter as a basis for calculation of actual stress. Simple geometrical considerations indicate that if this assumption is valid, the actual percentage compression under the same load must be slightly greater in *D* than in *B*, the actual mean stress behaving in the opposite way. So far, these deductions are in qualitative agreement with Cook and Larke's extrapolation, and with increasing initial height d_0 remaining unaltered, the stress value for equal loads in each case will rapidly converge to a *lower* limiting value.

The disagreement arises when geometrical speculation is confronted with actual observation, which suggests that the deformation pattern of a very slender cylinder, compressed without buckling, will be of the type *E* and not *D*. That two separate bulges appear when $h_0/d_0 > 2$, is too obvious to be disputed,[8, 9, 10] and this explains why the alleged reliability of the extrapolation method given in Fig. 10 is fictitious.

In fact, the mean cross-sectional area of the end bulges of deformation pattern *E* is always greater than that of the cylindrical portion, the latter having a smaller diameter than could be expected in the hypothetical, but untrue, case *D*. Hence the mean compressive stress is less in the bulges than in the cylindrical portion, and, with increasing h_0, the mean overall stress will actually *increase*, converging asymptotically toward the higher value appropriate for the cylindrical part alone. This shows that to obtain the correct stress value for h_0/d_0 equal to infinity, the constant strain curves *a–h*, in Fig. 10 would have to turn *upwards* on approaching the vertical $d_0/h_0 = 0$. As barrelling increases with μ, the mean stress value in slender specimens is bound to be less when end friction is high compared with low μ.

I agree that, when the length-to-width ratio is low, the undeformed material on each side of the gap may be the main factor causing plane strain. In general,

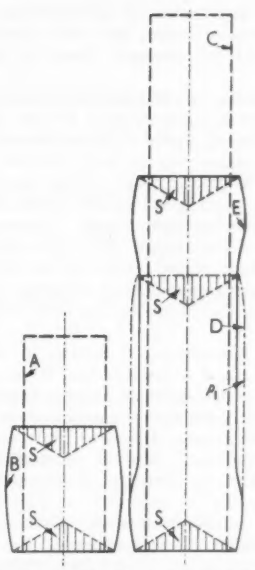


Fig. G—Shape of originally short (*A*) and tall (*C*) cylinders after 40% compression (*B* and *E*). The outline *D* does not occur in practice.

and according to prevailing views, it does not matter, from the viewpoint of the deformed material, whether the spread in one direction is prevented by roll-face friction, by guide plates, or by any other means.[11]

If a compression test were performed with narrow tools on a thick slab, a large error might be involved in the range of small deformations because of the peening effect.

The stress *T*, in Fig. 16, is radial in an axially compressed cylinder, and is horizontal in two-dimensional compression when the external force is vertical and the third stress component is zero.

Any variation of roll load found experimentally by Dr. Ford can be accounted for by a reasonable change of μ. His further observation on Figs. 26 and 27, in which he points out that friction has to change in two directions with speed, is apparently caused by a misunderstanding. Such a change of roll force as is shown is not only explained in Figs. 23 and 28, but is essential to the whole of my concept. I cannot see why the data of Table IV should refute my explanation, particularly if the works of Dokos[6] and Bristow[7] are considered.

Even if the 'dents' in Figs. 27 and 31 were caused by the Keller effect, the mean effective coefficient of friction must have increased in these cases. Such a conclusion will be reached from consideration of the spread (Fig. 35) or of the geometry of the roll gap, or even by trying numerical methods.

In reply to Mr. Gibson, creep may partly account for the difference between the curves produced by Taylor and Quinney, and by myself. One of my specimens was compressed up to 96%, and left for 1 hr. under load. The final d/h value was about 2, *i.e.*, 8 times less than Taylor and Quinney's value; the Vickers value was 133–134, and the actual stress decreased to 29 tons/sq. in. This figure for actual stress is still much higher than 26·1. Most sources quote values of over 30 tons/sq. in. for copper heavily deformed by compression (Ford), tension (Swift), drawing (Bolton, Smart), or rolling (Ford), and there is no reason to consider the value 26·1 as more reliable than the others.

Excessively slow rates of deformation in industrial forming processes are rare, and the values given in my diagrams should be assessed from a practical viewpoint.

Kuntze's results, quoted by Professor O'Neill, could be explained by a consideration of the relative size of the " cap of stagnant metal " formed around the indenter in the case of either low or high friction. Such a cap represents a non-plastic zone, which could be regarded as a protruded portion of the tool ; this zone would be larger if the indenter were rough. Consequently, equilibrium between immersion and work-hardening of the sample would be reached earlier in the latter case, than if the cone were smooth and greased. The apparent hardness would, therefore, be less with low μ, in accordance with Fig. A.

I think Mr. Hessenberg is correct in suggesting that the actual deformed volume is less when μ is high, and that the work of deformation is accordingly less. Many experiments with plasticine models were made in the past (Kick,[3] Rummel, Orowan), but only qualitative results were obtained, and it is unlikely that more information than is already known could be gained in this way.

Mr. Watts' contribution shows that, by using incremental compression, it is possible to get almost homogeneous deformation up to over 50% reduction of height. This being so, I cannot see why he says that my own cylinders were inhomogeneously deformed after as little as 25% compression, since I used precisely the same procedure as he. Further, if the whole cylinder is homogeneous, an axial portion machined from it must also be practically homogeneous, because there is no reason for a pronounced Bauschinger effect to appear in this case.

I am not clear to what Mr. Watts is referring in his second point. My statement in the last passage on p. 256 refers to the range of heavy deformations when the breadth-to-thickness ratio is of the order of 4 ; under these conditions the high stress values are certainly caused by friction.

I agree that the range of applicability of the plane compression test can be widened by using narrower tools at a later stage (stepped compression).

In Fig. B the close agreement between the three curves is most likely due to the use of incremental loading during compression before extrapolation. In that case the slope of the constant reduction curves must have been zero (or almost zero) near the y-axis. Furthermore, too great discrepancies in experiments with soft copper cannot be expected, as was pointed out in the paper.

Since Dr. Desch made his suggestion I have found that Bridgman conducted tests on similar lines.[13] His work was confined to two-dimensional compression tests and moderate deformations of up to 33%. In this range the stress/strain curve for high μ was systematically about 5% below that obtained with efficient lubrication. The conclusion reached by Bridgman was that " if anything, the average stress for non-homogeneous distortion is less than for homogeneous distortion," and this bears out the most debatable point of my own conclusions.

Ludwik's conception, as regards the possible identity of tensile and compressive stress/strain curves, is approximately correct for ductile non-ferrous metals such as copper, aluminium, and Monel, but it does not seem to hold for carbon and low-alloy steels. This statement is based on Siebel's, as well as my own, experimental results. I am glad that Mr. Caswell was able to show that the qualitative theory presented in the paper can be supported by a simple, and readily understood, mathematical treatment. I think that the physical background of Mr. Caswell's deductions is not unlike that of Mr. Hessenberg's, and it is interesting to note that my basic idea has so much in common with the early concept put forward by Mr. Caswell. However, there is one weak point in both Mr. Hessenberg's and Mr. Caswell's suggestions, because the argument of the smaller active volume, while applicable to compression, does not seem to hold for continuous processes, like rolling. There is no trace of slip cones in cold-rolled bars, and ultimately the whole volume is work-hardened. The problems associated with the mechanism of friction are unfortunately complicated, and the recent review by Finch[12] shows how much has yet to be done in this field.

In reply to Mr. Brace, I can confirm that I observed that it is better to use somewhat shorter cylinders at the later stages of compression ($h/d = 1{\cdot}5$) to prevent buckling.

All the stress curves given in the paper can be readily recalculated in terms of load as a function of diameter. A reference to Fig. 18 indicates that the load/strain curves are rather steep for over 50% reduction, even when the test piece is initially slender. The slope increases rapidly with decreasing h_0/d_0 (*see* Figs. 1 and 2). A comparison of these Figures shows that rough and dry plates act so as to depress the position of the critical point by shifting it to the lower reductions.

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Joint Discussion on the Papers—

DISTRIBUTION OF MATERIALS IN THE BLAST-FURNACE
Part II—COMPENSATED CHARGING* *by H. L. Saunders and R. Wild*

INVESTIGATIONS ON AN EXPERIMENTAL BLAST-FURNACE†
by H. L. Saunders, G. B. Butler and J. M. Tweedy

and A RADIO-ACTIVE TECHNIQUE FOR DETERMINING GAS TRANSIT TIMES IN A DRIVING BLAST-FURNACE‡ *by E. W. Voice*

Dr. **H. L. Saunders** (British Iron and Steel Research Association) introduced the first and second papers.

Mr. **E. W. Voice** (British Iron and Steel Research Association) presented his paper and added: The technique has since been extended to take simultaneous samples from two points on the stockline—at the centre and 1 ft. from the inwall.

So far, only six results have been obtained, and all were taken on one furnace. Figure A shows that:

(i) In general, all six results are similar. The activity starts and reaches its peak at the wall in less time than for corresponding phenomena at the centre

(ii) In general, the peak activity reaches the walls in approximately 1 to 3 sec., whereas for the centre it may take 3 to 9 sec.

(iii) Activity persists at the stockline for 8 to 10 sec., even though the introduction of the radon takes only a few milliseconds.

On this particular furnace, therefore, the following phenomena are generally observed at the stockline: (*a*) The value of CO_2 in the blast-furnace gas is lower at the wall; (*b*) gas temperatures are higher at the wall; (*c*) the rate of descent of the burden is greater at the wall; and (*d*) the gas transit times are less at the wall, which suggests higher velocities at the walls.

Gas velocities cannot be deduced from these experiments because the paths taken by the gases and the porosities of the materials in the stack are not known. However, when information is obtained on more furnaces, including sampling at more points, it may be possible to ascertain the paths taken by the gases and the time taken over shorter distances.

Mr. **R. P. Towndrow** (Messrs. Colvilles, Ltd.): In so far as the two papers on compensated charging and the experimental blast-furnace are complementary, it is convenient to consider them as a whole. The problem of circumferential distribution in the blast-furnace has been very largely solved by mechanical devices, such as the McKee top. In fact, it might be said that, after the invention of hot blast and the establishment of control over circumferential distribution, all subsequent progress in iron-making has lain solely in efforts to improve radially controlled distribution. This has been tackled chiefly from the angle of improved size-grading of the material, thus lessening the importance of radial segregation.

Within certain limitations, three facts are firmly established by the present investigation. Firstly, the distribution patterns predicted from slice and circular models can, when appropriately interpreted, be reproduced in a furnace which will actually make pig iron. Secondly, the distribution in the experimental blast-furnace as interpreted from iso-CO_2 lines and isothermals is closely analogous to the similar patterns obtained in the full-scale field test at Frodingham. Thirdly, these

* *Journal of The Iron and Steel Institute*, 1949, vol. 163, Sept., pp. 61–70.
† *Ibid.*, 1949, vol. 163, Oct., pp. 173–206.
‡ *Ibid.*, 1949, vol. 163, Nov., pp. 312–315.

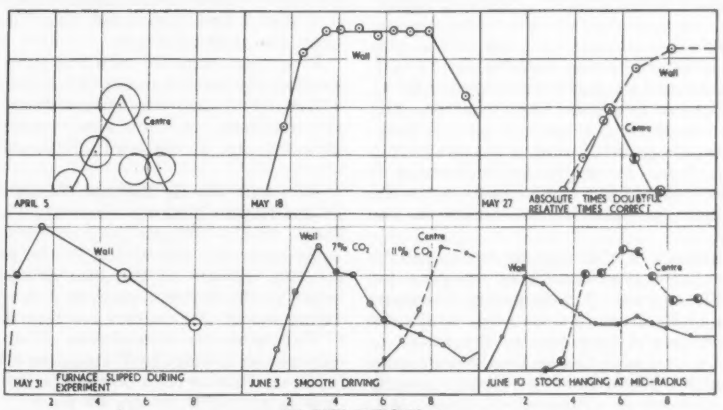


Fig. A—Typical stock-line contours at No. 3 Furnace, Corby

distribution patterns, so interpreted, can be altered by suitable means of charging control.

The object of carrying out these experiments on a furnace of that particular size was that it was hoped to acquire very much closer control over unwanted variables than is normally obtained in commercial practice. It is, therefore, unfortunate that detailed results are given for only 16 days' work out of a period of 13 weeks when the furnace was in operation, and when operation appears to have been fairly steady for about 63 days—as shown by the coke consumption. Indeed, one of the test periods lasted for only five 8-hr. shifts. It would be interesting to have even a few data for the other periods of normal operation, because it should be possible to determine the variability of what is ostensibly constant practice, so as to obtain an idea of the significance of variations which are the result of deliberately produced changes in practice.

During the four test periods there were variations in the slag volume and, presumably, in the burdening of the furnace, which appeared to be significant. In examining the results, it appears that the carbon consumption in the four test periods varied with the slag volume in a normal manner. Incidentally, it would be interesting to know the significance of the almost constant difference between the calculated and observed slag volumes. It may be possible, therefore, making due allowance for the variation of slag volume, that the change in coke consumption attributed to distribution control would become insignificant.

On p. 206, conditions are stated to be colder in period 2 than in 1 and 3, but that statement is contradicted by the published temperature records for the slag and metal, although I admit that one can say that a furnace is ' cold ' when, by anything one can measure, it is not cold.

Dr. Saunders, to advance his arguments to a stage which I think is not justified, says that the *coke* rate for period 3 is lower than for period 1. I recall that period 3 was when a particular form of compensation was introduced. The *carbon* consumption is actually lower in period 1 than in period 3—in fact, it is the lowest carbon consumption in all the four test runs. Therefore, it seems to me that, allowing also for the slightly higher slag volume in period 1, the only conclusion which can be drawn from the figures for the iron analysis is that conditions in the furnace were slightly better in period 1, as normally charged, than in period 3 with compensated charging.

There is a very large variation in the amount of flue dust, which does not appear to be reconcilable with the estimated fines content of the burden. Another significant feature about the operation of this furnace is the very low silicon and high sulphur contents of the iron produced. It appears that the slag analyses are normal, and that the slag and metal temperatures are some 50° C. lower than those obtained in normal basic practice. The desulphurization is of particular interest, and is practically negligible from the point of view of the production of commercial pig iron. It would be interesting if deductions could be drawn from these results as to the mechanism by which desulphurization occurs in the normal blast-furnace.

As one of the objects of this experiment would be to assess improvements in performance by compensated charging, I should like to know if, in the practical running of the furnace, the limit of ore-to-coke ratio which the furnace would carry was determined by the metal or slag temperature, by iron analysis, or by the regularity of stock movement? These are the factors usually considered by the operator of a full-scale furnace. Was the ore-to-coke ratio at all times as high as the furnace could carry, and yet continue to work as a furnace?

It is difficult to assess what has been achieved by the deliberate variations in distribution. If judgment is based on variation of carbon consumption only, the best performance appears to be in period 1. On the other hand, if performance is assessed on the mean CO/CO_2 ratio, period 1 is the worst. If slag volume is allowed for in the assessment, period 3 seems to be worse than period 1, but again the picture is reversed if the CO/CO_2 ratio is considered.

I have attempted to make an empirical correction of the carbon figures from a consideration of the slag volumes, and, taking approximately 30 lb. of carbon for 100 lb. of slag volume, and correcting the figures to the same slag volume, the order of merit of the four trial periods becomes 1, 3, 4, and 2. If the CO/CO_2 ratio is regarded as the criterion, the order becomes 4, 2, 3, and 1.

After allowing for the slag volume, the variations in carbon consumption are small, namely, 2270, 2386, 2300, and 2381. The significance of these variations in carbon consumption appears to depend upon a knowledge of the magnitude of the variations during a somewhat longer period of normal operation.

Dr. Saunders invited practical operators to view with some alarm the possible consequences of such a drastic change in materials distribution as was made in the experimental furnace, but to me there appears to be some evidence that such a drastic change is actually experienced in full-scale operation. Mr. Voice has shown how, on the furnace on which his experiments were carried out, the velocity and temperature of the gases were very much higher at the wall of the furnace than at the centre. I believe that in previous experiments on the velocity of stockline movement the same applied, namely, that the travel of the stockline was much faster at the walls than at the centre, which is the reverse of the normal distribution pattern on the experimental furnace and, indeed, of what would be anticipated from the characteristics of that furnace. Nevertheless, it works quite well as a normal blast-furnace, and it does seem that one could accept, without undue alarm, the complete reversal of the distribution pattern.

Mr. **J. Russell Taylor** (Igranic Electric Co., Ltd.): For a good many years I have been designing mechanism for the distribution of charges in the blast-furnace, and I have been wondering how segregating the charge, or preventing it from spreading in a radial manner, might affect the control of furnaces.

I was pleased to hear that the problem of charging in a circumferential direction has been solved. There are many ideas on the method of rotating the McKee top, and I had concluded that the method depended upon the shift manager.

From our point of view the most sensible method is to drop the same number of loads at each position, say, 45° or 60° apart, but, nevertheless, to be able to vary the numbers. Are my ideas correct, or is it better to drop at, say, 0°, 180°, 90°, 270°, and so on?

Monsieur **Ch. G. Thibaut** (Institut de Recherches de la Sidérurgie, Longwy, France): The authors' development of the oxygen-gain calculations has led to an important new conception of the process. Is the high sulphur content of the iron caused by the high heat losses in the tuyere region, or is it caused by inadequate reduction of the burden reaching that zone?

The work on distribution is of great interest. My impression is that the **V** stockline is much more common in Great Britain than on the Continent, where the stockline is generally of the **M** form.

Has the author tried, or is he trying, to measure gas velocities in different regions of the stock column?

Mr. **R. P. Towndrow**: I should like to assure Mr. Russell Taylor that the modern McKee top is capable of great flexibility of operation. If the blast-furnace manager cares to entrust his shift manager with making these alterations, there is nothing to prevent him, and all that is required is an adjustment of the controls on the distribution panel.

Dr. **H. A. Dickie** (Messrs. Stewarts and Lloyds, Ltd.): The authors have succeeded, in both papers, at least in demonstrating the similarity of the flow patterns between the small-size experimental furnace and the laboratory models. Whether they have succeeded in showing that this really represents the patterns in production furnaces may be open to considerable argument.

The natural desire of the authors to counter, as far as possible, objections to the lack of similarity between the small furnace and a production furnace may have led them into greater practical and experimental difficulties than necessary. They have, for example, used the common high limestone practice, giving a lime/silica ratio of 1·3 to 1·4.

The only reason for using excess limestone in the burden is to absorb the sulphur into the slag and to produce a low-sulphur iron; this has not been produced in the small furnace. The limestone has been surprisingly ineffective in removing sulphur into the slag, the percentage of sulphur retained in the slag being only 75% in period 1, and 65% or 64% in the other three periods. The sulphur in the iron produced varies from 0·35% to 0·50%, which are very high figures, the more so since the ores used contained very little sulphur, and the coke sulphur was by no means high. This appears to indicate lack of contact between the limestone flux and the sulphur in the charge, presumably largely because of the time factor, and in this respect the small furnace has been far removed from the production furnace in action.

Blast-furnace reactions are so complicated, and are so difficult to isolate from one another, that I would suggest the adoption of a simplified procedure in any further campaign, either on a small furnace or on a larger furnace. One of the complicating factors in assessing the blast-furnace reactions must be the presence of carbon dioxide combined in the materials of the burden. This could be avoided by suitable treatment of the materials where necessary, and particularly by running the furnace with a burden designed to give a slag with a lime/silica ratio of unity—in other words, the acid process, sometimes known as the neutral process. It would also be possible to remove sulphur from the coke, if that were desired, but in the acid process, in normal practice, a sulphur removal of 80% into the slag is obtained.

In these ways, a burden free—or substantially free—from carbon dioxide, free from carbon monoxide and, if desired, low in sulphur, could be used with various advantages in following the course of the reduction reactions. Furthermore, improved fluxing of the gangue would be an important accompanying benefit, owing to the more intimate contact of the constituents within the charge, and the greater fusibility. The result should be a smoother-running furnace.

Mr. Voice's experiments are of interest as preliminary steps in the application of radio-active isotopes to works problems in the iron and steel industry. Radio-active isotopes of all the 96 known elements have either now been synthesized or, in a small proportion of cases, are present in the natural state, but a great many of them are too short-lived for experimental use in industry. It thus happens that Mr. Voice used radon when, for example, radio-active nitrogen would have been much more appropriate, since there would then have been no possible objection because of dissimilarity between the radon and other constituents in the gases. The projected use of xenon is one step nearer to similarity, and it will be of interest to know, in due course, how the results obtained with xenon compare with those using radon.

Mr. **M. P. Newby** (British Iron and Steel Research Association): To appreciate fully Mr. Voice's work there must be some knowledge of previous work on this subject.

Kinney* used a pitôt tube to measure gas velocities, and this apparatus, being of non-standard design, had to be calibrated in a type of wind tunnel. His pitôt tube had the dynamic tapping on the side and the second tapping on the end. We at B.I.S.R.A. find that the pressure differential between the two tappings on a tube of this sort is higher than that on a normal pitôt tube. Kinney, in his calibration, which was carried out in a non-standard type of wind tunnel, obtained pressure differentials less than those of a normal pitôt, and his estimates of velocity are, therefore, probably too high. Kinney pushed his pitôt tube into a bed of solid materials and assumed that the pitôt factor remained unchanged, whereas there is undoubtedly an extra pressure drop caused by the tight packing of material round the tube. Therefore, for a given velocity, the pressure differential was greater than it would be in a free stream. Most of Kinney's measurements would be expected to give velocities at least twice as great as they should be. This, I think, is reflected in his estimated area voidage of 8% in the blast-furnace. One would expect a figure twice, or three times, as great. However, I should not completely rule out the future use of pitôt tubes if these were calibrated properly in a bed of materials, and the voidage were estimated separately by other methods. If it were found that the tube calibrations depended little upon voidage and distribution of size of materials, then they would have application.

Mr. Voice has not attempted to estimate any velocities from his work, but, assuming a voidage factor for the blast-furnace, as Kinney did, his figures are very much closer to what one would expect. His mean transit velocities are approximately one third of those which would be deduced from Kinney's results.

Mr. **E. L. Diamond** (British Standards Institution): It may add to the completeness of the discussion to say that the engineering problem of carrying out the experimental method of distribution control on a full-size blast-furnace has been tackled at B.I.S.R.A., and the results will be published shortly. A design has been prepared which I think would effectively carry out Dr. Saunders' proposals. How far it would be free from trouble in working would be difficult to say, but it does, I think, represent a serious attempt to solve the difficult problem of providing a mechanism to move and control distributing elements within the gas space of the furnace.

Nevertheless, recognizing these difficulties, we sought an alternative which would avoid the introduction of moving parts into the furnace. This was achieved by dividing the ordinary big bell horizontally into two parts. The upper part is a small cone, and is the moving element which opens and closes the hopper and discharges the material. The lower frustum is permanently fixed in the furnace in the lowered position, and constitutes the distributing element. If the cone, or moving part, can be lowered rapidly inside or through the fixed frustum (which is suitably profiled inside), as well as to

*S. P. Kinney, "The Blast-Furnace Stock Column." *U.S. Bureau of Mines*, 1929, *Technical Paper*, p. 442.

the normal open position, the discharge can be to three annular zones of the stockline surface, namely, the centre, the wall zone, and an intermediate zone. This proposal does not afford quite such a wide degree of compensation as is afforded by the device described by Dr. Saunders, but it would probably be a more acceptable arrangement for everyday operation.

Sir **Charles Goodeve,** F.R.S. (Director, British Iron and Steel Research Association): These three papers add to our knowledge of what goes on inside a blast-furnace. Furthermore, they already form part of the basis for technical developments in plant and process. The most important of these is the Radcon top, which permits substantial control of the chemical and physical composition of the burden in the radial direction. The principal object would be, of course, to permit more uniform, and hence faster and more efficient, working of a furnace, but this top could also aid in curing hanging and scaffolding by a change in the ore, coke, or limestone content in the outer ring of the burden. After the McKee top, I look upon this as the next major step forward in the evolution of the blast-furnace, and it should, among other things, remove the present limitations on hearth and stack diameters.

Mr. Voice's results may reopen the arguments as to the best stack angle. The fact that the gas was found to rise so rapidly along the wall may indicate that there is too much batter, and that the burden does not expand enough to fill the increasing diameter. I am sorry that the top-wall sample was taken a foot in from the wall, rather than at the wall, as this introduces a time delay that may be appreciable.

A number of speakers, and in particular Mr. Towndrow, have given various reasons why the sulphur ratio (slag to iron in the experimental blast-furnace) is so low. While not disagreeing with these speakers, I should like to emphasize that the biggest factor in affecting the capacity of slag to absorb sulphur is the oxygen potential. In the reducing conditions of a normal blast-furnace, sulphur ratios as high as 100 can be obtained, whereas in the higher-oxygen-potential conditions of the open-hearth furnace, ratios down to unity are often found. It is to be noted that the oxygen potentials of the slags from the experimental blast-furnace are unusually high, judging from the iron content, and hence a low sulphur ratio is to be expected.

Dr. **R. V. Riley** (Staveley Iron and Chemical Co., Ltd.): Mr. Voice's methods of using radon for large-scale industrial research will clearly gain prominence, and it would be interesting to have some idea of the approximate cost of an investigation such as this.

AUTHORS' REPLIES

Dr. **H. L. Saunders** wrote in reply: I shall reply briefly to the question on the possibility of a reversal of the distribution pattern in the Corby furnace. I do not think this, in fact, happened, but there must have been a reversal in furnace operation. With that particular furnace, having a bell/throat ratio of about 0·75, we should expect a well-defined **V** stockline contour. That would mean a concentration of fines near the wall. Lower down the stack, fines would still be in the wall region, though they might be fritted together or even partially melted.

We should also have to consider what would be happening at the tuyeres, because a compacted mass in front of the tuyeres could, within a limited blowing range, become a decisive factor in determining whether or not the blast penetrated the barrier thus set up. A slight fall in blast would cause working up the wall, while a rise would permit penetration to the more open structure of the central column. Results at a later date, when some 60% of sinter was incorporated in the burden showed that conditions were entirely different. This would be anticipated, for the fines content of the burden would necessarily be diminished and the barrier effect on the blast would be lessened. Thus the furnace would show a greater tendency to work up the centre.

Mr. **G. B. Butler** wrote in reply: It must be remembered that the experimental furnace was not planned or intended to be run as a normal operating furnace, but that its main purpose was the investigation of conditions in the stack.

The furnace was operated as closely as possible to a normal furnace, and blast volume and temperature conditions were determined and maintained at which the furnace worked satisfactorily. The burden was kept constant, and the fluctuations in iron and slag analyses were mainly attributable to normal variations in the analyses of the raw materials.

The daily operation of the furnace was decided by the cast-to-cast analysis of the iron, the appearance of the metal and slag, and the separation of iron and slag when casting. All iron issuing through the slag notch with the slag was allowed to separate. It was then weighed and the reasonable working of the furnace was shown by the obtaining, in this way, of only 8 cwt. of iron from the last 250 casts made.

The sulphur content of the iron produced was certainly higher than that from a normal-sized furnace with similar slag conditions. We consider that this was probably due to the very shallow depth of the slag layers in the hearth.

With regard to the published data, these cover the periods in which stabilized conditions had been achieved and maintained. The remaining portion of the campaign included periods in which the bells were changed, the distribution sequence was changed, and periods of operating troubles, such as tuyere changes, after each of which stabilized conditions had again to be restored before tests of definite value could be resumed.

With regard to the significance of the almost constant difference between calculated and observed slag volumes, we can only reply that we do not know.

Mr. **E. W. Voice** wrote in reply: Dr. Dickie questioned the use of radon rather than radioactive nitrogen. Unfortunately N_{13} has a half life of 10 min. and N_{16}, although a powerful γ emitter (5 m.e.v.) has a half life of 7·3 sec. Both, therefore, are useless for this work. Xenon and Krypton would be preferable, because of suitable radioactive properties and their lower atomic weights, but these are not yet available commercially at an economic price.

Sir Charles Goodeve regretted that wall samples were taken at 1 ft. from the wall. The reason for this was that sampling tubes were lowered down spare stock rod holes. In future we hope to arrange sampling tubes so that gases may be withdrawn at any two positions on the stockline, and a true wall position will be used.

In reply to Dr. Riley's question about cost, the price of radon is about 2*s.*/mc., and the cost for each experiment on a 20-ft. dia. blast-furnace is, therefore, about £4.

I was grateful to Mr. Newby for his comments on Kinney's pitôt tube. Kinney used a tube of 1½ in. dia., and the distance between the static and dynamic tubes was approximately 2 in. I suggest that such a tube in a blast-furnace burden might easily measure mainly the pressure drop through 2 in. of burden and not the dynamic head. I agree that elaborate and realistic calibration is essential, but, if pitôt tubes are used, I consider that it would be essential to use tubes of very small diameters.

Discussion on the Paper—

PLASTIC STRAIN AND HYSTERESIS IN DRAWN STEEL WIRE*

by R. S. Brown

Mr. **G. K. Rylands** (Messrs. Rylands Bros., Ltd.) presented the paper on behalf of the author.

Dr. **C. H. Desch,** F.R.S. (Past-President) : Some attention has to be given to the conditions of the wire when it is made into a mine rope and fixed into the cap when soldering. When I was in Sheffield, I had to investigate several colliery accidents which occurred because of failure in the capping, where the heating effect of the solder came into play.

Dr. **H. A. Dickie** (Messrs. Stewarts and Lloyds, Ltd.) : The paper is worthy of study by all those interested in the effects of cold-working on steel, although its applications relate exclusively to wire products. It provides those not engaged in the wire industry with another example of the remarkable range of useful properties which can be obtained from steel by varying the manufacturing and heat-treatment methods.

The author has demonstrated very clearly that, for applications requiring highly stressed flexible wire, the wire should not possess true elasticity, and, further, how this non-elastic flexibility can be ensured in the wire by cold-drawing, with the avoidance of the restoration of the elasticity by ageing or heating. His method of plotting the stress/strain curves by the increment of strain against stress is very interesting, and has successfully disclosed features which cannot be recognized on the conventional stress/strain curve using the same results. It reminds me of the differential method of plotting thermal heating and cooling curves, which leads to similar benefits in following the changes.

It is interesting to realize that there are important uses of steel in which it is a disadvantage to have elasticity and high elongation, and in which, in fact, low elongation is essential. Wire which is cold-drawn, even when precautions have been taken to prevent accelerated ageing, will, of course, strain age-harden within a few days of manufacture. The author indicates, quite rightly, that flexing of the wires themselves to the extent of permanent set will wipe out the ageing changes and restore the plasticity. Steel which is cold-worked to a fairly severe extent and allowed to age-harden will then, on further cold-working, become softer. The proportion of the hardness which is caused by ageing will be partially or fully removed by further small amounts of cold-working.

Does the author consider that wire ropes should be put into service before the full ageing effect has occurred, and be used sufficiently continuously in service to avoid waiting periods, during which ageing, with its restoration of elasticity, may occur ?

The galvanizing treatment is, from the author's point of view, a heat-treatment, producing certain changes in the wire itself, as distinct from any benefits conferred by the coating. The heating cycle embodied in the galvanizing process generally improves the physical properties of a cold-drawn product ; internal stresses are partially removed, the steel is slightly softened, the elongation and reduction of area, and also the notch impact value are improved. In the present application, however, all these apparent benefits are nullified completely by the restoration of elasticity and rigidity in the steel. Does the author attribute the shorter life of galvanized wire solely to the restoration of elasticity, or would he attribute any part of the deterioration to the presence of the galvanized coating, which contains, of course, brittle zones just below the surface.

There is, I think, an anomaly in the paper. The author demonstrates, in Fig. 9, that hot-galvanizing restores elasticity, yet the elasticity is apparently not restored in the hot-galvanized wire described on p. 198, and shown in curve 1 of Fig. 16. I think also that, at the top of p. 193, curve *E* in the text should be curve *A*.

The author considers it essential to avoid a rise of temperature during the drawing process, but he gives no details of the improvement obtained by efficient cooling methods. Does he find any differences in the heat evolved in steels of different composition ?

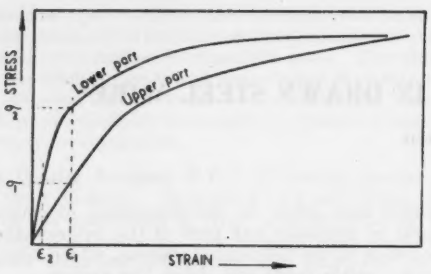
In a footnote on p. 190 the author endeavours to distinguish between creep at ordinary and at elevated temperature ; he appears to say that high-temperature creep does not diminish with time. It does diminish with time until increasing extension of the test piece raises the stress, or, indeed, until something 'mathematical' occurs to the test piece, after which accelerated creep sets in. Similar effects occur at ordinary temperatures in the necking-down stage of the tensile test, so that it is difficult to see how a distinction can be made between high- and low-temperature creep on the basis attempted by the author.

Mr. **W. C. F. Hessenberg** (British Iron and Steel Research Association) : In disputing the use of Hooke's law in engineering metallurgy, the author has proved the importance of the shape of the lower end of the stress/strain curve where it is neither linear nor insensitive to metallurgical treatment. It might be complained that the author has suggested nothing in the place of Hooke's law. It is to fill this gap that the Wire Drawing Committee of B.I.S.R.A. are examining the relationship between acceptance tests for wire, the stress/strain curve, and the behaviour of wire in service.

The behaviour of the signal wire seems to be clear from a study of Fig. 14 and from the fact that both the heat-treated and the cold-drawn wire are bent round the same diameter over the shoe in the anchorage. Because of the steeper slope of the stress/strain curve of the heat-treated material, a higher stress is induced in it. In the case of the colliery ropes, however, the argument seems to be less convincing. I wonder whether the overriding factor there is that the lower part of the rope is constantly submitted to the stresses imposed by the cage, whereas the upper part rests for part of the time by being over on the other side of the pulley, so that the active life of the lower part is obviously much greater than that of the upper.

Apart from this difference in service conditions the stress/strain curves of the upper and lower parts are different, as shown by the author. That of the lower part is rather steep, whereas that of the upper part, owing to repeated bending round the pulley, is shallower. What fatigue conditions are imposed on the rope ? If the conditions are such that the fatigue strains are

* *Journal of The Iron and Steel Institute*, 1949, vol. 162, pp. 189–200.



σ_1 and σ_2 = stresses induced by the strains ϵ_1
ϵ_1 and ϵ_2 = strains induced by the stresses σ_1

Fig A—Stress/strain curve for lower and upper part of wire

comparable, the strains would induce a much higher stress in the lower part of the wire than in the upper part (*see* Fig. A); but if the same stresses are imposed, the area under the stress/strain curve for the upper part of the wire is greater than that for the lower. The difference in behaviour between the upper and lower parts of the rope is consistent with the fatigue strains being nearly the same in both.

Mr. **T. H. Turner** (British Railways): It is significant that the operation of drawing a wire leaves residual tension stresses and that many wires fail by corrosion-fatigue. Is there any insuperable objection to a wire being finished by a reduction process which does not depend on dies and tension, but which uses shot or multiple hammer peening under controlled rotation, so that all parts of the wire surface go into service with a uniform residual compression stress?

Uncoated wires are relatively scarce, for the largest tonnage is coated with zinc because of corrosion and to prevent corrosion-fatigue.

Dr. Evans and his colleagues have shown that shot-peening assists resistance to corrosion-fatigue.*

I believe that for the larger-section wires, such as are used for railway signals and fencing, increases in service life are to be expected if the finishing process is comparable with peening rather than with drawing.

AUTHOR'S REPLY

Mr. **R. S. Brown** wrote in reply: Dr. Dickie asked whether wire ropes should be put into service before the full ageing effect had occurred. Many ropes, particularly those used for colliery winding, are maintained in store as spares for a considerable length of time. Although some ageing occurs the effect is slight compared with the pronounced changes that can be induced by low-temperature heating or repeated loading. No difference has been noted between the lives of ropes placed into immediate service and ropes taken from stock.

The deterioration of drawn patent steel wire following upon hot galvanizing is caused by the change in elastic properties.

Dr. Dickie draws attention to an anomaly in the curves of Figs. 9 and 16. The wire in Fig. 16 is of small diameter and has, therefore, been through the galvanizing bath at considerable speed. In consequence, the tempering effects are not severe.

The rise in temperature during drawing is proportional to the horse power involved, and as the horse power increases with increasing carbon content, greater difficulty is experienced. For this reason it is frequently necessary to reduce speed when drawing material with a very high carbon content.

Objection was made to the use of the term "creep" when the paper was first presented for publication, and the footnote on p. 90 was introduced, at the suggestion of the editor, to avoid confusion with the term which is normally applied to the effect of loading at elevated temperatures.

Mr. W. C. F. Hessenberg's suggestion that the fractures at the capel end of winding ropes are caused by the stresses imposed by the cage is the one usually put forward. The author's alternative explanation is doubtless speculative, but the evidence presented in the paper would seem to give support to the theory. It is also suggested that the fatigue strain is higher at the point where the rope bends round the pulley, when it is bearing the full weight of the rope and load at the end, under conditions of acceleration. For equal stress/strain relationships, the stress should be at a maximum at the pulley. If this were true fractures could be expected to take place more readily at this point than at the end attached to the cage. It is unfortunate that the validity of this assumption cannot be checked on wires taken from a rope after service.

* *Journal of The Iron and Steel Institute*, 1948, vol. 160, pp. 164–168.

Discussion on the Paper—

THE EFFECT OF SODIUM OXIDE ADDITIONS TO STEELMAKING SLAGS
Part I—USE OF SODA TO DEPHOSPHORIZE PIG IRON AT 1400° C.*

by W. R. Maddocks and E. T. Turkdogan

Mr. **E. T. Turkdogan** (Sheffield University) introduced the paper.

Dr. **F. D. Richardson** (British Iron and Steel Research Association): The new results which Dr. Maddocks and Mr. Turkdogan put forward in their paper are of considerable technological and fundamental interest. From the technological standpoint they are best summarized by Tables I and II, and Figs. 8 and 15. I shall not deal further with this aspect of their work, because almost any treatment or method of representing the results is adequate for technological purposes, though it may have no fundamental significance. I do, however, differ with the authors on the fundamental explanation of their results.

I should like to ask if the authors really obtained equilibrium between slag and metal in their heats, for only if they did so have their results any serious quantita-

* *Journal of The Iron and Steel Institute*, 1949, vol. 162, pp. 249–264.

tive significance. In nearly all their experiments the final slags contained high percentages of FeO, although the carbon content of the irons was between 1·5 and 2%. Experiment *NSI* (Table II) shows a 1·03% carbon iron at 1400° C. in contact with a CaO–FeO–MnO–SiO_2 slag containing 29·65% of FeO. The experiments of Taylor and Chipman* on the equilibria between iron and CaO–FeO–SiO_2 slags indicate that such a slag would be in equilibrium with iron containing about 0·09% of oxygen at 1600° C., and would thus have an FeO activity (relative to pure FeO) of about 0·4. This activity would not be expected to decrease markedly as the temperature falls to 1400° C., for the author has already shown by calculation from the FeO–SiO_2 phase diagram that the activity of FeO in FeO–SiO_2 melts is not strongly influenced by temperature.† An extrapolation of Taylor and Chipman's results on the solubility of oxygen in liquid iron suggests that at 1400° C. the limiting value would be 0·07%, so that the value in equilibrium with the *NSI* slag should be approximately 0·03%. This should be in equilibrium with about 0·1% of carbon instead of the 1% recorded in Table II.

The authors' experiments consisted of heating soda-bearing slags with iron containing carbon and phosphorus, as may be represented by the figures,

(Na_2O)	(SiO_2) (CaO) (FeO)
[C]	[P]
2·9	1·3

When the slags contained 20–30% of silica, 30–40% of lime, and finished with approximately 10% of Na_2O, they lost large amounts of soda during the experiments. Pure Na_2O does not boil until temperatures above 1600° C. are reached,‡ so that it is extremely improbable that it could be vapourized in large amounts at atmospheric pressure from silicate slags, even though these contain calcium.

On the other hand, it is known that sodium oxide should be reduced by carbon to sodium vapour and CO (both at 1 atm.) at about 1000° C., and sodium silicate (Na_2SiO_3) should be reduced, even in the presence of silica, at about 1700° C.§ Since the silica in the silicate slags of Table IV must be present at a much lower activity or chemical potential than that of pure silica, this reduction process will be possible at much lower temperatures. This, therefore, seems the most probable mechanism for the loss of sodium in the Series *C* experiments in Table I. The sodium vapour produced would, of course, re-oxidize at the first opportunity and form the white fumes of Na_2O reported by the authors, gas oxidation, according to them, being inevitable. The mechanism proposed in equation (6), on p. 256, cannot be accepted, as sodium silicates are quite definitely more stable than calcium silicates. At 1400° C., the standard free energy of formation of solid calcium silicate is — 21 kg.cal., and that of solid sodium silicate is — 58 kg.cal. The stabilities of the corresponding phosphates are far greater, the free energies of formation from oxide and P_4O_{10} vapour at 1400° C., being — 132 kg.cal. for $Ca_3P_2O_8$, and — 229 kg.cal. for $2Na_3PO_4$. Thus it is to be expected that the presence of phosphate in the slag may lower the Na_2O activity sufficiently to keep it from being reduced to, and lost as, sodium vapour.

In the second series of experiments (Table II), the silica activity is sufficiently high, and the soda activity sufficiently low, to prevent this reduction to sodium. Good dephosphorization can, nevertheless, be obtained, because of the far larger free energy of formation of sodium phosphate than of sodium silicate.

I cannot agree with the validity of the authors' treatment concerning the so-called dissociation of fayalite. As I understand it, the object of these calculations is to determine the oxygen potential (or the FeO activity) of the slag, and to correlate it with the percentage elimination of phosphorus. So far as I am aware there is no way of doing this *via* the fayalite dissociation constant, and I do not believe that the authors' calculations are justified. In this connection it is of interest to note that $a_{(FeO)}$ in slag *NSI* has been roughly estimated in the second paragraph of my remarks as 40%, whereas the authors' calculation for $(FeO)_{free}$, which is meant to correspond to the activity, gives approximately 14% (Table VI).

The only use which could be made of the fayalite dissociation constant D is through the equation,

$$a^2_{(FeO)} \times a_{(SiO_2)} = a_{(Fe_2SiO_4)} \times D$$

If any two of the activities are known in any slag it is possible to calculate the third. As it is, none of them is known. The standard thermodynamic treatment of solutions should be applied.

Dr. **C. H. Desch**, F.R.S. (Past-President): During the First World War the Government suggested the recovery of potash from certain ores by putting salt into the blast-furnace to volatilize potassium chloride. That was done. After one furnace was blown out we took some bricks from the upper part and they were found to be 50% soluble in water. I came out of that furnace very quickly, because the lining might have come down at any time. Some potash was recovered, but, of course, it ruined the furnace. One has to be very careful in introducing alkalis into a slag because of the possible damage to refractories.

CORRESPONDENCE

Dr. **P. T. Carter** (Royal Technical College, Glasgow) wrote: The authors, while making a valuable contribution to the use of soda in dephosphorization, have attempted to explain the difference between the behaviour of soda in acid slags and lime-bearing basic slags in terms of the replacement of soda by lime from combination as silicates in the case of the latter slags.

Three years ago we became interested in the use of sodium oxide as a slag component with desulphurizing and dephosphorizing powers, which, at the same time, would give low melting slags. We commenced our study with an investigation of the Na_2O–FeO–SiO_2 system. Our slags were made in iron crucibles at 1220° C., and the more basic slags showed considerable loss in weight during preparation. These slags also contained high percentages of sodium oxide, and were of the same order of basicity as the basic slags of the authors, though not containing lime. At first this loss was attributed to volatilization of sodium oxide, but analysis indicated a considerable difference in composition between the initial mixture and the final slag, which could not be explained solely by such volatilization, *e.g.*:

	Na_2O, %	FeO, %	SiO_2, %
Initial mixture	26·96	42·36	30·68
Final slag	17·19	51·45	31·36

The ferrous oxide content of the slag had increased

* C. R. Taylor and J. Chipman, *Transactions of the American Institute of Mining and Mechanical Engineers*, 1942, Technical Publication, 1499.

† F. D. Richardson, *Transactions of the Faraday Society*, 1948, vol. 4, p. 244.

‡ E. J. Kohlmeyer and E. G. Bunzel, "F.I.A.T. Review of German Science," 1939–46, *Inorg. Chem. IV*, p. 200.

§ F. D. Richardson and J. H. E. Jeffes, *Journal of The Iron and Steel Institute*, 1949, vol. 163, p. 407.

at the expense of sodium oxide, and this was attributed to the reaction:

$$\underset{\text{slag}}{Na_2O} + Fe \rightleftharpoons \underset{\text{vapour}}{2Na} + \underset{\text{slag}}{FeO} \quad \text{.....(1)}$$
(solid)

The free-energy change for this reaction is not known accurately, but an approximate value may be given as:

$$\Delta G^\circ_{\sim 1500^\circ K.} = 92{,}800 - 61{\cdot}1T$$

Hence, at 1220° C.:

$$K = \frac{(a_{FeO})p^2_{Na}}{(a_{Na_2O})}$$

The activities of sodium and ferrous oxides are not known, but if (a_{Na_2O}) were equal to (a_{FeO}), $p_{Na} = 0{\cdot}77$ atm., which is quite considerable. Even if (a_{Na_2O}) only equals $0{\cdot}01$ (a_{FeO}), $p_{Na} = 0{\cdot}077$ atm.

The free-energy change at 1400° C. for the reaction

$$\underset{\text{slag}}{Na_2O} + Fe \rightleftharpoons \underset{\text{vapour}}{2Na} + \underset{\text{slag}}{FeO} \quad \text{.....(2)}$$
(liquid)

is known with even less accuracy, because of the higher temperature to which the available data must be extrapolated, but K is certainly much higher, its value at 1400° C. being approximately 19, indicating an even greater tendency to lose sodium as sodium vapour by the reaction (2). Volatilization of sodium oxide could, of course, still occur.

It is clear, from the authors' work, that sodium phosphate is not reduced in this fashion, being quite stable in the presence of molten iron. That, despite this, sodium oxide in basic slags does not promote dephosphorization can be explained if reaction (2) is much more rapid than that in which sodium oxide combines with P_2O_5 to form sodium phosphate. In acid slags the activity of sodium oxide is apparently lowered to a greater extent than that of ferrous oxide by silicate formation, it being, of course, a more strongly basic oxide. Sodium phosphate must be formed in acid slags by the reaction of the phosphorus pentoxide resulting from oxidation of the phosphorus in the metal with sodium silicates, possibly through the intermediary formation of ferrous phosphate.

AUTHORS' REPLY

Dr. **W. R. Maddocks** and Mr. **E. T. Turkdogan** wrote in reply: We consider that the main significance of the research at this early stage lies in the considerable industrial potentialities of a process that would remove phosphorus from an iron at 1400° C. under relatively acid slags on acid hearths.

The work has been successfully developed on an assumption of molecular dissociation of slag compounds, and an assessment of the 'free' components thus arising. We were aware that a conception of 'activities' would be more fundamentally correct, but the evaluation of such quantities could only be done by experiment and they would vary, possibly very considerably, with slag composition and temperature. It was felt that the 'activity' and the assessed 'free' amount of a component in a slag would give results which were similar.

In conducting the experimental melts, care was taken to maintain the temperature of the bath within ± 10° C. of the temperature chosen, until little or no reaction was visible in the furnace. It was noticed that, under these conditions, the rate of removal of carbon was slow, but that by raising the temperature, or by adding an oxidant, a reaction could be started. Most of the slags in question contained high percentages of ferrous oxide, so that if the carbon reaction ceased under these conditions it was reasonable to conclude that the rates of reaction were approaching those of equilibrium conditions. We did not claim absolute equilibrium conditions in the experiments. It is interesting to contemplate that, had such conditions existed, the figures for the removal of phosphorus could have been improved.

That the removal of carbon ceased under slags containing high percentages of ferrous oxide must mean that the total ferrous oxide content of the slag is not active. We have suggested that it was combined as fayalite, since all the conditions that were considered to promote the dissociation of fayalite produced a more oxidizing slag, as evidenced by the further removal of carbon.

Dr. Desch's remarks on the possible effects of alkalies on the refractories were most informative. One of the features of this work was that the minimum amount of sodium oxide—seldom more than 6–8% was used—was necessary for the removal of the phosphorus. Since an excess of sodium oxide was not required for the completion of the reaction, its effect on refractories should be slight. There is no doubt, however, that work on this aspect of the problem must be carried out.

We thank Dr. Carter for his contribution. It appears that iron plays an important part in the loss of sodium oxide from the slags, and the reactions suggested by Dr. Carter and Dr. Richardson seem to be the most reasonable. During the progress of the research, however, many peculiar features were noticed. For example, the loss of sodium oxide was greatest in more basic slags, especially those containing lime, but it was not apparent in siliceous slags. It was also found that the addition of molten iron to a synthetic slag containing soda, silica, and iron oxides did not produce a fume. It appeared that the reduction of sodium oxide by iron could only occur under conditions of slag composition that produced free sodium oxide. There was always the possibility of the sublimation of this free sodium oxide.

Discussion on the Paper—

CHANGE OF ELECTRICAL RESISTANCE DURING STRAIN-AGEING OF IRON*

by A. H. Cottrell and A. T. Churchman

Professor **A. H. Cottrell** (Department of Metallurgy, University of Birmingham) presented the paper.

Dr. **H. A. Dickie** (Messrs. Stewarts and Lloyds, Ltd.): The authors have successfully demonstrated, in a most interesting way, that strain age-hardening is accompanied by a decrease in electrical resistance. Some thirty years ago, Campbell showed that the ageing of

* *Journal of The Iron and Steel Institute*, 1949, vol. 162, pp. 271–276.

carbon steels following quenching was accompanied by a decrease in the electrical resistance, which continued for a period of two years, and probably longer. His tests did not, however, distinguish between the quench-ageing of ferrite solutions and of martensite. It appears, then, that in both strain-ageing and quench-ageing the first action is an increase in the resistance by the act of cold-working or quenching, and this is followed by a decrease in the resistance during the subsequent ageing period.

Some of the properties of steel act in a similar way during cold-working and ageing. For example, the hardness and tensile strength are increased by cold-working, and further increased by ageing, while the notch impact values decrease in both stages. Other properties, including the resistivity, go in the opposite direction in the ageing period. The yield point and elasticity of the steel are destroyed by cold-working and are restored by ageing, with corresponding alterations in the liability to stretcher strains.

The authors assume that the number of dislocations produced by increasing amounts of cold-work is proportional to the change in resistance on ageing, or to the amount of carbon transferred to the dislocations. In this way they attempt to explain the constant ageing period at a constant temperature with varying amounts of cold-work. I suggest that they might consider the quench-ageing of ferrite by their precise methods of testing, since a variation in the quenching effect, in that case, will presumably not be accompanied by an alteration in the number of dislocations. It is known that when quench-ageing is most severe it is completed, or practically completed, much more quickly than when the quenching effects are slight. The application of their methods to quench-ageing may, therefore, enable them to confirm, amend, or extend their theories.

There is no mention in the paper of the effects of concentration of the atoms of the element which produce ageing ; this strikes me as a weakness in an otherwise closely and well-reasoned case. It might be assumed, from what the authors say, that increasing the amount of cold-work affects only the number of dislocations, and that the subsequent ageing effect occurs at each centre at a given speed at a constant temperature. Increasing the amount of cold-work would, to my mind, be expected to increase the supersaturation of the elements concerned, with a correspondingly increased pressure of these atoms towards separation. The concentration of the initial solution certainly produces results of a most pronounced character. For example, as the nitrogen content of ferrite is increased, a standard amount of cold-work, which would, according to the authors, produce a standard number of dislocations, produces a correspondingly greater amount of strain age-hardening and embrittlement. Similarly, in the case of quench-ageing, the greater the supersaturation of the solution, the greater and more rapid is the completion of age-hardening.

Figure 6 in the paper shows that no hardening occurs in the first 30 min. of the ageing period, whereas there is a drop in resistance of about a quarter of the total change. The shapes of the hardening curve and resistance curve in Fig. 6 are also quite different. I do not doubt that both changes have the same underlying cause, but can the authors explain why the hardening does not follow the change in resistance ?

I would not dispute that carbon and nitrogen are major causes of the age-hardening of steel, but they are not necessarily the only causes. The removal of these elements, by treatment in hydrogen gas at elevated temperatures, removes the susceptibility to quench-ageing, and also to strain-ageing, to a large extent. For example, quenched metal shows no age-hardening after the carbon and nitrogen are removed, or at least lowered considerably, and the graph of hardness against time is very nearly a straight horizontal line.

In practice, this treatment is used in the production of mild steel, which is required to be of high permeability and to have a low hysteresis loss. The removal of carbon and nitrogen is not, however, generally practicable for many reasons. Therefore, a steel which is reasonably free from troublesome effects must be controlled in other ways. This can be done by refining the grain size, by lowering the nitrogen and phosphorus within working limits, and by other expedients in special cases.

Dr. **C. H. Desch,** F.R.S. (Past-President) : I am sorry to see that in discussions of this kind no reference is ever made to the work of Beilby* ; although it is quite out of fashion now, I should be inclined to regard the Beilby view as giving a satisfactory explanation of most of these facts. Towards the end of the paper the authors say that it might be argued that cold-working causes carbon and nitrogen to precipitate from solid solution. Is that not contrary to what is usually found, namely, that cold-work favours the passing into solution of those foreign atoms ? That is certainly my experience.

CORRESPONDENCE

Dr. **G. B. Greenough** (Royal Aircraft Establishment, Farnborough) wrote : Whereas I am, in general, in agreement with Dr. Cottrell's explanation of the yield phenomenon in mild steel and the associated explanation of strain-ageing, I consider that the present paper cannot, by itself, be regarded as providing overwhelming support for the explanation.

Since it is well established that the elastic straining of a metal changes its electrical resistivity, it is clear that any plastic working of the metal will also produce such a change. If there is any relaxation of elastic strain after plastic working, the resistivity will change slowly. This is a possible explanation of the experimental results, although it seems an unlikely one, since there is probably little relaxation of strain at room temperature, even in very localized regions of great strain. However, it may be that the only conclusive method of eliminating the possibility is to repeat the electrical resistance measurements on iron free from carbon and nitrogen.

The value obtained for the heat of activation from the variation of the rate of change of electrical resistance with temperature is about 20,000 cal./mol. This agrees with values quoted in relation to the diffusion of nitrogen and carbon in iron. These values are obtained from internal friction measurements, *e.g.*, as made by Kê,† and the mechanism of this process is assumed to be the moving of nitrogen atoms from one interstitial position to the neighbouring position and back, as the stress fluctuates, *i.e.*, a very short range diffusion in a particular crystallographic direction. The diffusion process postulated by Dr. Cottrell and Mr. Churchman must move the nitrogen or carbon atoms through several atomic diameters in a random direction through the iron crystal, and this is not necessarily a process with the same activation energy.

However, Kê has examined a second internal friction phenomenon, which is associated with the presence of nitrogen in iron. The mechanism of the process is not understood, but Kê has shown that it must be caused

* " Aggregation of Flow of Solids," London, 1921 : Macmillan.

† T.-S. Kê, *Metals Technology*, 1948, Technical Publication No. 2370.

by the diffusion of the nitrogen through the iron. Experimentally it is found that the process is greatly influenced by cold-working the iron, a fact closely linking this process and the strain-ageing phenomenon. The diffusion distance involved is shown by Kê to be a few atomic diameters. But the heat of activation of the process was shown to be approximately 32,000 cal./mol., a value very near to that obtained by ' classical ' methods at high temperatures (Barrer* quotes 34,000 cal./mol.).

I should be very glad if the authors would resolve this apparent discrepancy.

Dijkstra† recently published some internal friction observations which show that, in an iron containing nitrogen, after cold-working and ageing the nitrogen is effectively removed from solution and yet no precipitate is microscopically visible. Unfortunately no activation energy for the process was obtained, but the observation generally supports Dr. Cottrell's explanation of strain-ageing.

It seems, therefore, that although the electrical resistance measurements made by Dr. Cottrell and Mr. Churchman are generally consistent with the dislocation atmosphere theory of the yield point, they do not, at the moment, completely substantiate the theory.

AUTHOR'S REPLY

Professor **A. H. Cottrell** wrote in reply : Dr. Dickie's first point concerns the relation of quench-ageing in iron to the present work on strain-ageing. In a piece of iron or mild steel freshly quenched from 650–700° C., there may be up to 0·02% of carbon in solution. Unless the density of dislocations in the metal is as high as 10^{12}/sq. cm., which is unreasonable for an unworked sample, this amount of carbon is much more than is required by the dislocations. Most of it has to precipitate as carbide particles. Dislocations and grain boundaries may act as centres for nucleating these particles, but in any case quench-ageing has to be considered as a problem in the kinetics of the nucleation and growth of a precipitate. In regard to the effect of the degree of supersaturation on the rate of quench-ageing, this is usually explained in the theory of precipitation-hardening, on the basis that increasing the supersaturation decreases the critical size which a nucleus must attain before it tends to grow rather than to re-dissolve. The rate of quench-ageing is increased partly because small nuclei can form more quickly than large ones, and partly because the diffusion path between neighbouring nuclei is short when a large number of small nuclei are formed. The process of quench-ageing in iron has been studied recently in detail by Wert and Zener.‡§ Altering the concentration of carbon and nitrogen atoms will undoubtedly affect the rate of strain-ageing. In certain circumstances, for example, when there are more dislocations than can be satisfied by the amount of carbon or nitrogen present, or by that in solution, the degree of strain-ageing should also be affected.

Why the hardness does not change in the first 30 min., whereas the resistance falls during this period, is interesting. The explanation may be that during the early stages of strain-ageing, when the dislocations are only lightly anchored by a few solute atoms, the force needed to break them free is smaller than that needed to drive them through the various internal stress fields in the lattice. The hardness would then be determined by these stress fields until the strain-ageing process proceeded further towards completion.

Beilby's theory of a vitreous phase on the slip planes, mentioned by Dr. Desch, meets with the following objections : (*a*) The density of energy released on a slip plane when slip takes place is usually much lower than the density of the latent energy of fusion ; and (*b*) slip always takes place along a crystallographic direction, even when this is not the direction of maximum resolved shear stress, which shows that the crystalline field is at least partly preserved in the slip planes during slip. Because of these objections we did not try to interpret our results in terms of this theory. On the other hand, a slip plane containing many dislocations, in a cold-worked metal, is similar to one which is lined with a vitreous phase so far as certain thermodynamical properties are concerned ; both are sources of high free energy and may thereby attract solute atoms from undistorted parts of the crystal. It would thus be possible to explain some of the observations of the present paper in terms of Beilby's views.

Dr. Desch raised the question of whether cold-working favours the solution or the precipitation of foreign atoms. It is well known that cold-working promotes precipitation in supersaturated solutions. No doubt Dr. Desch was considering the more difficult question of what happens when a material containing a solute in an amount which is near to the solubility limit is deformed. We think that the answer depends upon whether solute atoms in dislocations are regarded as being in solution or not. If they are, then the limit of solubility is increased by cold-working, but if the other view is taken then cold-working favours the removal of solute atoms from solution.

In regard to Dr. Greenough's first point, we did not consider strain relaxation a reasonable explanation for our results because commercial iron softens appreciably only at much higher temperatures than were used in our work.

Concerning the mechanism of interstitial diffusion, we believe that macroscopic diffusion is the integrated result of a large number of jumps of the kind studied by Kê. This is supported by the recent work of Stanley,‖ who showed by ' classical ' methods that the activation energy for the diffusion of carbon in ferrite is about 18,000 cal./mol., which agrees with the value that we used. The activation energy of 34,000 cal./mol., quoted by Barrer, refers to the diffusion of carbon in austenite. Kê's second internal friction peak, in cold-worked iron containing nitrogen, is intriguing but not yet understood. It is caused possibly by the movement of dislocations accompanied by nitrogen.

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* R. M. Barrer, " Diffusion in and through Solids," 1941, p. 227. Cambridge : The University Press.

† L. J. Dijkstra, *Journal of Metals*, 1949, vol. 1, p. 252.

‡ C. Wert, *Journal of Applied Physics*, 1949, vol. 20, p. 943.

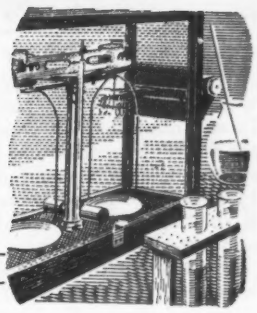
§ C. Wert and C. Zener, *Ibid.*, 1949, vol. 20, p. 950 ; *Ibid.*, 1950, vol. 21, p. 5.

‖ J. K. Stanley, *Journal of Metals*, 1949, vol. 1, pp. 752–761.

This completes the discussion on papers presented at the Autumn General Meeting held in November, 1949. The previous discussion on other papers was published in the November issue of the *Journal* (pp. 186–212).

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



Contribution of the Source Unit to Variability in Spectrographic Analysis

By the Spectrographic Analysis Sub-Committee

SYNOPSIS

A more comprehensive assessment of source behaviour, based on the technique outlined in an earlier paper, has confirmed that about 20–50% of the total error in spectrographic ferrous analysis, using photographic recording, can be traced to source contribution. Some of the factors affecting this contribution and the possibilities of improved source performance are considered.

THE Spectrographic Analysis Sub-Committee was formed in 1946 under the auspices of the Methods of Analysis Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association. Its constitution in 1949 was as follows :

Mr. S. D. STEELE (*Chairman*)	Babcock and Wilcox, Ltd.
Mr. A. ARGYLE	British Cast Iron Research Association
Dr. G. L. J. BAILEY	British Non-Ferrous Metals Research Association
Mr. L. J. L. BAILLIE (left 31st March, 1949)	David Brown Foundries, Ltd.
Mr. K. DIXON	B.S.A. Group Research Centre
Mr. J. M. JOHNSTON	Babcock and Wilcox, Ltd.
Mr. G. L. MASON	The United Steel Companies, Ltd.
Mr. G. P. MITCHELL	Philips Electrical, Ltd.
Mr. J. H. OLDFIELD	Bragg Laboratory, N.O.I.D.
Mr. W. D. OLIPHANT	Ferranti, Ltd.
Mr. H. T. SHIRLEY	Brown-Firth Research Laboratories
Mr. H. G. SHORT	National Physical Laboratory
Mr. R. H. TYAS (joined 31st March, 1949)	Edgar Allen and Co., Ltd.

At the first meeting of the Sub-Committee, when the formulation of a research programme was discussed, the relative performance of spectrographic source units was one of the problems which appeared to merit particular attention. Units available for investigation represented almost the entire range of equipment then in use (late 1946), and co-operative examination and comparison of the behaviour of the following spectrographic sources were made :

Two Dietert Multisource and earlier models
One Feussner controlled spark unit
Nine Hilger condensed spark units
One Metro-Vickers L.V. controlled source
Three B.N.F. general-purpose units
Various experimental modifications.

The results of the work carried out using the Hilger unit in the Brown-Firth Research Laboratories,[1] and later the results of a detailed study of the Metro-Vickers unit in the same Laboratories[2] were made known to the members of the Sub-Committee at an early stage, and it was decided to conduct an investigation along similar lines using the remaining units at their disposal. The essential purpose of the work was twofold ; firstly, to see whether other available Hilger units behaved similarly to the one already examined, and secondly, to check how far members' normal equipment and operating technique maintained or improved on the results obtained with the optimum conditions indicated in the earlier work. Some preparatory investigation was carried out by a small Study Group, and the details of the main programme were prepared.

Procedure

Steel samples 12-in. long, cut from a 35-mm. dia. bar of En 25 steel (Basic Electric Arc Cast No. 98164), were circulated. The routine analysis of this material was :

0·28% C, 0·29% Si, 0·53% Mn, 0·013% Si, 0·015% P, 0·83% Cr, 2·74% Ni, 0·49% Mo.

A check analysis for chromium was carried out at both ends of the bar and gave figures of 0·83% and 0·82% on single tests.

The bar was supplied in the oil-hardened and tempered condition, corresponding to 60–70 tons/sq. in. tensile strength.

Paper MG/D/244/49 of the Spectrographic Analysis Sub-Committee of the Methods of Analysis Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, received 18th March, 1950.

The essential details of the procedure were based on those used by Shirley, Elliott, and Meeds.[1] It was shown that, of the plates tested by these authors, Ilford Thin Film Half Tone would be expected to give the smallest contribution to error, and that the slow speed of the plates could, if desired, be partially offset by bringing the source nearer to the spectrograph. Kodak *B*10 plates would probably give the next smallest contribution.

Readings of the first 30 undamaged spectrograms were carried out on two independent 0·5-mm. lengths from each line. The standard deviation σ_T, corresponding to total variability, was then calculated from the variation between the 60 individual log ratios and their mean, according to

$$\sqrt{\frac{\Sigma d_T^2}{59}}.$$

The small-scale photographic plate contribution, σ_P, was based on the differences between the two independent log ratios from each line-pair, according to

$$\sqrt{\frac{\Sigma d_P^2}{2 \times 30}}$$

and σ_S, the excitation contribution, was calculated as

$$\sqrt{\sigma_T^2 - \sigma_P^2}$$

and converted into terms of percentage of element content.

Although both σ_T and σ_P carry residual reading errors these are of a similar order, and the error involved in σ_S by neglecting the difference was considered sufficiently small to cause no misinterpretation in comparing the results. The magnitude of the probable error is shown in Table I, where σ_{SC} is the true source contribution calculated from corrected values of σ_T and σ_P.

Results

The response of various line-pairs was assessed during the examination of these source units, and the results are summarized in Table II. No very significant differences were indicated in the performance of any of the sources under the conditions of test.

Origin of Errors

The proportion of the total variability contributed by excitation varies with different elements and line-pairs. Values of the standard deviation obtained by Shirley, Elliott, and Meeds,[1] are given in Table III in terms of percentage of element content. The results were obtained using a condensed spark circuit; no better results have been achieved by the use of the newer interrupted-arc circuits.

The figures indicate that from a quarter to two-thirds of the total variance is contributed by the excitation response, the remainder occurring in the recording and measurement of spectra. It is possible that the recording and measurement errors may prove to be reducible by a factor of ten by the substitution of photoelectric for photographic observation. This aspect is also under consideration by the Sub-Committee and will be the subject of a later report, but it is nevertheless evident that there is room for an appreciable reduction in the source errors.

Source Errors

Although there is little detailed analysis of source errors available, consideration must undoubtedly be

Table I

COMPARISON OF VALUES FOR σ_{SC} AND σ_S*

Line-Pairs	Mean Photometer Readings,† cm.	*RXB*329		*RXB*358		*RXB*359	
		σ_{SC}	σ_S	σ_{SC}	σ_S	σ_{SC}	σ_S
Fe 2799·29 II / Fe 2793·89 II	10 / 7	0·0017	0·0014	0·0021	0·0018	0·0021	0·0019
Fe 2788·11 I / Fe 2793·89 II	10 / 7	0·0026	0·0025	0·0035	0·0033	0·0027	0·0025
Ni 3515·05 I / Fe 3513·82 I	7 / 8	0·0013	0·0007	0·0011	0·0005	0·0022	0·0020
Mo 2816·15 II / Fe 2813·61 II	18 / 20	0·0029	0·0028	0·0029	0·0028	0·0018	0·0016
Si 2881·58 I / Fe 2885·93 II	32 / 22	0·0046	0·0045	0·0038	0·0037	0·0018	0·0015
Cr 3408·76 II / Fe 3404·36 I	21 / 25	0·0024	0·0022	0·0044	0·0043	0·0046	0·0045
Cr 2870·43 II / Fe 2858·87, 2868·45 II	26 / 22	0·0024	0·0022	0·0021	0·0019	0·0017	0·0014
Cr 3021·56 I / Fe 3016·18 I	33 / 31	0·0027	0·0025	0·0024	0·0023	0·0018	0·0015

* Based on Table X of ref. 1
† Related to a 50-cm. clear emulsion reading

given to (1) the metallurgical condition of the sample, (2) electrode geometry, and (3) electrical features.

Metallurgical Condition of Sample—It is recognized that errors may occur as the result of segregation, or because constituents may be strongly bound, *e.g.*, as compounds, to a variable extent depending on metallurgical history. Steps are taken, whenever possible, to minimize such errors, and although these effects may not at present be the main cause of errors they might represent a fundamental limitation of any improved method based on the use of solid electrodes.

Electrode Geometry—Highest accuracies are obtained only when close attention is paid to the form of the electrodes and their separation. The best geometries have been derived empirically, but it is widely agreed that they are forms which give the most uniform distribution of spark attack over a 2–3-mm. dia. disc on the sample surface. In general, the geometry should be such that as high a proportion as possible of the several thousand successive discharges used for a single exposure should occur between points of the electrode surfaces which have not been disturbed by previous sparks.

Electrical Features—The condensed spark equipment usually employed in this country is the Hilger set. The circuit is shown in Fig. 1. It comprises a 0·25 kVA. high-reactance transformer with secondary tappings giving open-circuit voltages ranging between 8 and 15 kV. r.m.s. A capacity of 0·005 μF., which nominally forms, with the transformer leakage reactance, a circuit resonating at the supply frequency, stores energy, which is discharged through an inductance of up to 0·4 mH. and through the analytical gap.

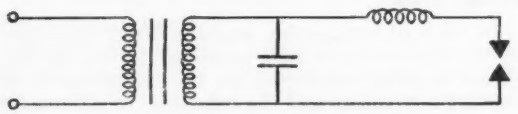


Fig. 1—Circuit for Hilger condensed spark equipment

With this circuit, one or more heavily damped oscillatory pulses of current pass through the analytical gap each half-cycle of the supply, *i.e.*, the fundamental discharge frequency is 100 cycles/sec. The oscillation frequency of individual discharges is of the order of 1 millicycle/sec. and there may be several such trains at intervals of about 0·5 msec. in each half-cycle of the supply. The peak current in each discharge is about 100 amp.

Oscillographic studies of the instantaneous currents in condensed spark discharges show

(*a*) that there is a marked variability in the interval between the initiation of discharges in successive half-cycles

(*b*) that there is a wide scatter in the peak currents passed at corresponding maxima in successive half-cycles.

Even when the initiation of successive discharges is controlled to occur at more regular intervals, no improvement in accuracy is obtained. Such control does not reduce the variability of peak current referred to in (*b*).

A much greater regularity of current has been achieved in several recently designed source units.

Table II—SOURCE CONTRIBUTION TO VARIABILITY

Operator	Source Unit	Primary, V.	Resistance, Ω	Transformer, kV.	Added Inductance, μH.	Capacity, μF.	Gap, mm.	Source to Slit, cm.	F1025 Lens to Slit, cm.	Pre-spark, sec.	Exposure, sec.	σ_S Calculated as a Percentage of Element Content								Mo 2816 / Fe 2813
												Line-Pairs (Cr/Fe)								
												2822 / 2823	2822 / 2827	2870 / 2868	2876 / 2877	3021 / 3016	3408 / 3404	3408 / 3413		
A	Walsh	260	3	...	0·06	8	...	20	2	2	45	...	...	...	1·3	...	...	...		...
A	Hilger	...	...	15	none	0·005	...	38	2	10	45	...	...	...	2·2	...	...	...		...
B	,,	...	...	15	,,	0·005	2·5	...	...	15	4 × 45	...	...	1·3	...	2·0	1·9	...		1·2
C	Feussner	120	...	20	,,	0·007	...	...	...	...	...	0·8	1·0	...	...	...	2·5	2·1		...
C	Hilger	120	...	15	,,	0·005	...	...	...	...	...	...	...	1·2	...	1·6	1·5	...		...
D	,,	...	...	15	,,	0·005	2·5	...	...	15	2 × 75	...	...	1·0	...	1·9	1·4	...		1·4
D	,,	...	...	15	,,	0·005	0·2	...	...	...	3 × 25	1·2	...	...	...	...	...	...		1·1
E	,,	...	...	15	,,	0·005	2	36	...	...	6 × 15	1·1	...	1·2	...	...	1·5	...		1·3
E	Dietert*	...	...	35	0·045	0·007	2	30	...	...	3 × 60	1·3	...	1·4	...	...	1·8	...		1·7
F	Hilger	...	...	15	none	0·005	2	36	2	none	6 × 15	1·4	1·6	...	1·5	...	1·6	1·9		...
G	,,	250	...	15	,,	0·005	2·5	38	2	15	2 × 60	...	...	0·8	...	1·7	1·5	...		0·9

* Power setting ¼ kVA.

Table III

PROPORTION OF TOTAL VARIABILITY CONTRIBUTED BY SPARKING RESPONSE*

Line-Pair	Sparking Response	Small-Scale Plate Variability	Photometry	Total	% Contribution of Sparking Response to Total
Si 2881·6 I / Fe 2885·9 II	2·20	0·88	1·29	2·70	67
Mn 2933·1 – / Fe 2936·9 II	1·24	0·55	0·82	1·59	61
Cr 2870·4 II / Fe 2868·5 II	0·91	0·91	1·36	1·87	24
Cr 3408·8 II / Fe 3404·4 I	1·52	0·78	1·17	2·07	54
Ni 3515·9 I / Fe 3513·8 I	0·81	0·65	0·97	1·42	32
Mo 2816·1 II / Fe 2813·6 II	0·90	0·72	1·08	1·58	32

* Based on data from Tables X and XIII of ref. 1

These provide essentially a low-voltage high-capacity condenser discharge (*e.g.*, 10 μF., 300 V.) which is initiated by a high-voltage pulse of short duration. In spite of the reproducibility of current waveform in successive discharges, the accuracy obtained in the analysis of steels shows no improvement, although that obtained in the analysis of non-ferrous alloys is greater than hitherto and is now in line with the accuracy of steel analysis. Both the total light emitted and that dispersed into selected wavelengths varies widely from spark to spark in spite of the highly reproducible current waveform. This waveform differs from that produced in the condensed spark, in comprising a lower current, of about 10 amp. peak, decaying during a period of about 1 msec.

Possibility of Improvement

Simplicity of sample preparation has always been considered of first importance by users of the spectrographic method, and the desire to retain this simplicity has limited the type of development work undertaken. The Committee considers that it is now important to decide whether the accuracy of the technique can be improved without loss of simplicity of sample preparation.

Two lines of development deserve consideration :

(1) To use the present principle, by which the functions of producing and of exciting the vapour are combined. It appears that accuracy increases as the duration of each discharge decreases, and that, while regularity of repetition and constancy of current waveform may be necessary conditions, they are not sufficient to give an improved result. If the discharges are short, their recurrence frequency might be increased and the peak current reduced so that more sparks would contribute to the integrated exposure. Movement of the metal electrode opposite a point counter-electrode, so that the discharge always attacked a fresh surface, might increase accuracy. The effects with atmospheres other than air, and at various pressures, also appear to merit a tentative exploration.

(2) To develop methods in which the production of vapour and its excitation are separate. This approach at least offers the possibility of eliminating the effects of metallurgical history and electrode geometry. The difficulty evidently lies in the production of the metal vapour.

Further Work

In view of comparable reproducibility evidenced by the various source units examined, further investigation is being conducted on the improvement of existing equipment and the behaviour of alternative methods of excitation. The findings will be the subject of a later report.

References

1. H. T. Shirley, E. Elliott, and J. Meeds : *Journal of The Iron and Steel Institute*, 1947, vol. 157, pp. 391–409.
2. H. T. Shirley, A. Oldfield, and H. Kitchen : *Journal of The Iron and Steel Institute*, 1950, vol. 166, pp. 329–338 (this issue).

Census of Fatigue Failures

At the annual meeting at Delft, in 1949, the International Institute of Welding decided to appoint a special commission on fatigue under the chairmanship of Professor M. Ros of Switzerland.

The Institute of Welding has accepted the responsibility for collecting data on fatigure failures that have occured to welded structures and machinery in Great Britian.

Similar enquiries are being made by other member organizations of the International Institute as a first step in an exhaustive investigation of the problems of fatigue.

A Statistical Study of the Behaviour of Spectrographic Source Units

By H. T. Shirley, B.Sc., A.R.C.S., A. Oldfield, and H. Kitchen

SYNOPSIS

Following up previous work on the statistical examination of the magnitude and origin of variability in spectrographic analysis of low-alloy steel, the authors have carried out a more detailed study of the influence of factors operative during excitation. The work includes a comparison of various types of excitation unit, particularly of the ordinary uncontrolled Hilger high-voltage condensed spark unit and the Metro-Vickers controlled low-voltage source.

Over 30,000 readings from more than 15,000 lines have been used. The results have permitted the selection of certain optimum conditions within the range of variables studied, and have shown that the most favourable results are obtained with the simple Hilger unit, operating with a graphite auxiliary electrode and a 2½-mm. gap. The use of air blast across the gap, the inclusion of a 15-sec. pre-spark period, or variation in the length of exposure over a wide range, showed no important effects on this reproducibility.

In addition to the main series of tests with the Metro-Vickers low-voltage source, the work with controlled units has included the use of a Metro-Vickers high-voltage unit, a Multi-source low-voltage unit, and a B.N.F.M.R.A. low-voltage unit. It is shown that under the optimum conditions tested, these controlled sources can give results approaching those of the simple Hilger unit for suitably matched line-pairs. The divergence tends to be much greater for less favourable line-pairs and extremely high variability may be found.

Introduction

A LARGE part of the total variability in spectrographic analysis is introduced by variation in excitation response, and strenuous attempts have been made to devise equipment and conditions capable of usefully reducing this variation. A widespread interest in this matter was shown by spectrographers at the A.S.T.M. Symposium on Spectroscopic Light Sources held in 1946.[1]

Attempts to improve excitation steadiness have centred mainly on development of source units in which the frequency of discharge and the general form of the charge/discharge voltage curve were strictly controlled. Much of the present study relates to the detailed comparison of results obtained from one such controlled source unit with those from a simple uncontrolled high-voltage condensed spark unit which is typical of the class extensively used in the past in metallurgical analysis.

A previous paper[2] has described the statistical procedure used in the authors' laboratory for assessing the magnitude of the individual contributions of the three major causes of the variation: variability in excitation response, inconsistency of the photographic recording, and variability in the photometric evaluation of the record. These individual contributions were expressed as standard deviations σ_{SC}, σ_{PC}, and σ_R, combining for total variability according to the equation

$$\sigma_T^2 = \sigma_{SC}^2 + \sigma_{PC}^2 + \sigma_R^2.$$

Both the earlier work and the present study have related to a single sample of nickel–chromium–molybdenum steel having the following analysis:

0·30% C, 0·25% Si, 0·58% Mn, 0·77% Cr, 2·75% Ni, 0·50% Mo.

As an indication of the relative importance of the three factors concerned, it was found that working with the lines Cr (II) 2870·43, Fe (II) 2868·45, 2868·87, a σ_T of 1·87% of the chromium content divided into contributions of 0·91, 0·91, and 1·36% for σ_{SC}, σ_{PC}, and σ_R. An alternative line-pair, Cr (II) 3408·76, Fe (I) 3404·36, having a steeper slope to the composition curve, but showing less satisfactory excitation steadiness, gave a total of 2·07% of chromium content made up in the proportions 1·52, 0·78, and 1·17%. It is evident that variability in excitation response formed an important part of the total, and can be the major contribution.

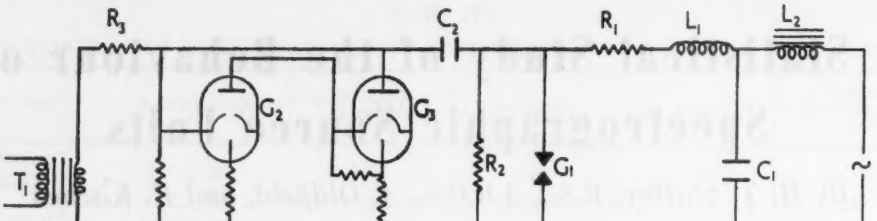
A prototype model of the Metro-Vickers' low-voltage controlled source unit, and later a slightly modified version, were made available by the makers, and a detailed comparison was made between these units and the Hilger uncontrolled high-voltage source unit previously used. Examination of the effect of various ancillary factors, such as the type of electrode system, the use of air blast, length of exposure, and choice of line-pairs, as well as variation in circuit parameters for the low-voltage source were included. A Dietert Multisource unit and a B.N.F.M.R.A. general-purpose unit were later made available by the British Non-Ferrous Metals Research Association, and a limited comparison with these units was possible under certain selected conditions.

EQUIPMENT AND TESTING PROCEDURE

For most of the work, the steel sample was in the form of a 2-in. × 1½-in. × ¼-in. piece cut from the 7-lb. box test ingot of nickel–chromium–molybdenum steel used in the earlier work.[2] This sample was

Paper MG/D/167/49 submitted by the Spectrographic Analysis Sub-Committee of the Methods of Analysis Committee of the British Iron and Steel Research Association (Metallurgy (General) Division), received 18th March, 1950. The views expressed are the authors' and are not necessarily endorsed by the Sub-Committee as a body.

The authors are on the staff of the Brown-Firth Research Laboratories.



R_1 = 0–90 Ω (variable) C_2 = 0·015 μF. L_2 adjusted to resonance with C_1
L_1 = 15–500 μH. (variable) R_3 = 11,000 Ω
C_1 = 1–11 μF. (variable) R_2 = 1M Ω T_1 = 11 kV. transformer

Fig. 1—Schematic circuit diagram of Metro-Vickers unit showing trigatrons and low-voltage power supply

sparked on a 2-in. × ¼-in. face after smooth filing. The upper electrode used in combination with this sample was either a $\frac{3}{16}$-in. dia. silver rod or a 6-mm. dia. spectroscopically pure graphite electrode with 80° points. In addition, some tests were carried out with ¼-in. dia. steel pencils, cut from the original box test sample and used together as an 80° pointed steel pencil combination.

The spark gap was used at $1\frac{1}{4}$, $2\frac{1}{2}$, or 4 mm. width : most of the work was carried out at $2\frac{1}{2}$ mm. This was set at the normal 38 cm. distance from the slit for most of the work, but a few plates were taken at 20 cm. to study exposure variation, or to shorten an impracticably long exposure with a weak discharge.

Excitation Equipment

Hilger High-Voltage Condensed Spark Unit—This widely used, simple, uncontrolled high-voltage condensed spark set consists of a 15-kV. transformer, rated at 0·25 kW. with a 0·005 μF. condenser in parallel with the spark gap. It was used without added resistance or inductance.

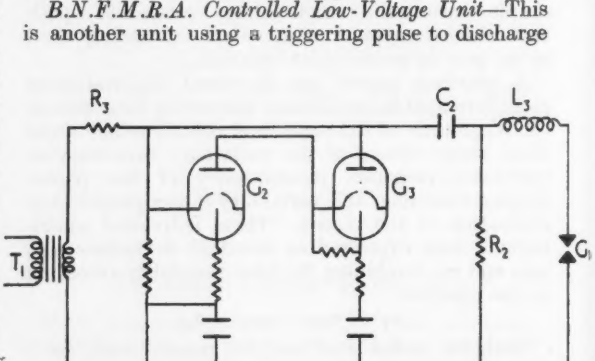
Metro-Vickers Low-Voltage Controlled Source—Most of the present study has been made with this low-voltage controlled unit, the operating principle of which has been described in detail by Braudo and Clayton.[3] Briefly, it consists of a triggering pulse circuit electronically synchronized to the 50 cycle mains to give one discharge per half cycle at a reproducibly selected point on the charging curve for the power condenser. In the set used, the trigger pulse was fed through trigatron gaps from a 10–11-kV. transformer, as indicated in the schematic circuit diagram shown in Fig. 1. The low-voltage follow-through discharge circuit operated at about 500V., built up by resonance of the inductance L_2 with the capacity C_1. The discharge was thus of an alternating type, each electrode being alternatively positive and negative at successive discharges. Variation in R_1, L_1, and C_1 (*see* Fig. 1), together with the shift in the phasing of the triggering, made available a wide variety of discharge conditions from the spark-like to the arc-like, and at varying power.

Initially the unit was operated with R_1, 0–90 Ω; L_1, 15–500 μH. ; and C_1, 1–10 μF., the triggering pulse being supplied by a 10-kV. transformer. After modification the capacity was altered to 11 μF. maximum and the triggering pulse was fed from a larger 11-kV. transformer.

Metro-Vickers Controlled High-Voltage Condensed Spark Unit—This was essentially similar to the low-voltage unit, except for the omission of the low-voltage follow-through circuit and increased power in the high-voltage circuit. This increased high-voltage power was achieved by modification of C_2, R_2, and R_3, as indicated in Fig. 2. The inductance L_3 was added to protect the equipment from a too great current surge through the gap.

Dietert Multisource Unit—This unit is similar to the Metro-Vickers unit in that it is employed as a synchronized high-voltage triggering pulse with a relatively low-voltage follow up, but the method of achieving this differs in several respects : synchronization is brought about by a rotary auxiliary gap which gives, through a rectifier, a unidirectional pulse every alternate half cycle. The principle of this equipment has been described by Hasler and Dietert,[4] and an account of its application to steel analysis has been given by Hasler and Kemp.[5]

B.N.F.M.R.A. Controlled Low-Voltage Unit—This is another unit using a triggering pulse to discharge



C_2 = 0·0085–0·034 μF. L_3 protective inductance of 30 μH.
R_2 = 2500 Ω T_1 = 11 kV. transformer
R_3 = 130k Ω

Fig. 2—Rearrangement of Metro-Vickers unit for use as high-voltage controlled source

the low-voltage power charge, but in this case rectification of high-voltage and low-voltage charges is arranged in opposite half cycles so that the low-voltage circuit is isolated from the charging circuit during discharge. It has been described in a paper by Walsh.[6]

Exposure

In all cases, except in the preliminary tests with the Metro-Vickers Unit, two superimposed exposures were used to produce each spectrogram, as in the authors' normal practice. The actual exposure time given varied from 30 to 360 sec. according to the source used, and was regulated so that the lines were read as far as possible within a range of 5–40 cm. with a 50-cm. clear plate photometer reading. In addition, to indicate any major effect that essential exposure variations might have on the variability, at some of the more important source settings exposure was varied over a four to one range, by varying the electrode-to-slit distance.

It has been the authors' normal practice to give a 15-sec. pre-spark before commencing the actual exposure, and this was made the normal practice in the present work. Omission of this pre-spark period was made in certain cases to check how far it was influencing the reproducibility.

Air Blast

The effect of an air blast directed on to the spark was explored by using twin jets set horizontally at 180° to each other and at 90° to the spark-slit axis. Each jet was 20 mm. from the spark centre, and air flowed through a 4·8-mm. dia. orifice at 35 litres/min. under a pressure of 6 cm. of mercury.

Photographic Technique

Thirty-four repetition spectrograms were taken on each plate. To minimize the photographic contribution to the total variability most of the work was carried out with Ilford Thin-Film Half-Tone plates, but the faster Kodak *B*5 plates were used for two series (*see* Table II). From earlier statistical studies[2] the variability introduced by the latter would, in terms of σ_{PC}, be expected to be about 50% greater than with the Ilford plates. Much of this contribution is, of course, removed in calculating σ_{SC}, and in the work on *B*5 plates the values of σ_{SC} were so large that the effect of any difference in residual photographic error would be too small to be of any practical importance.

The development and general processing procedure have been described in Appendix II of the earlier paper.[2] The Kodak squeegee-type development, in quarter strength *D*19*b* developer for 3½ min. at 18° C., was used. An acetic acid stop bath was followed by an acid-fixing bath, and the plates were all shelf-dried at room temperature.

Readings

Readings were taken, as in the earlier work,[2] using a model *H*451·306 Hilger densitometer, with compact galvanometer scale unit. The concentrated light beam was used, and the slit was set at 0·15 mm. width. Two independent 0·5-mm. lengths were read from each of the 1·7-mm. lengths of line available. For the statistical work, figures were used from the first 30 spectrograms for which reading of the various lines was possible without interference from obvious damage or plate defects.

The shortened reading method[2] (p. 400) was used. This avoided duplication of reading except where the initial log-intensity ratios obtained from the 'top' and 'bottom' readings of line-pairs, respectively, differed by 0·010 or more, in which case a check reading was made. The log-intensity values were deduced, as in the earlier work, from the mercury-vapour lamp time-scale type of plate calibration normally used by the authors.

Line-Pairs

It was necessary to limit these to six combinations, taken from the earlier work, because of the very large number of readings involved, which, even with this restricted series and the simplified reading procedure, is over 30,000. The actual lines used are listed in the tables of results. Table II includes the Harrison figures[7] for relative arc/spark intensities which cover, according to Harrison's Tables, (II)/(II) and (I)/(II) iron–iron pairs, (II)/(II), (I)/(I), and (II)/(I) chromium–iron pairs and a (II)/(II) molybdenum–iron pair. The nickel–iron pair Ni 3515·051–Fe 3513·821, which gave very good results in the earlier work, was omitted, because with the Metro-Vickers unit it gave lines too dense for satisfactory reading, even when the Cr (I) line was approaching the 40-cm. limit. The three chromium combinations were retained for comparison, and reduction in overall spectrogram densities was, therefore, not possible.

Statistical Treatment for σ_{SC}

The same procedure has been used as in the earlier work[2] (p. 400). Single readings of independent 0·5-mm. lengths were taken from corresponding positions for each line of the pair from the 1·7-mm. lengths available. These readings were checked, as described above, only when the log-intensity ratios from the two sets of readings differed by 0·010 or more. The resulting 60 log-intensity ratios for a given line-pair were then averaged for the whole plate and σ_T calculated as

$$\sqrt{\frac{\Sigma d_T^2}{59}}.$$

The value for σ_P was obtained as before from the 30 differences between the two log-intensity ratios from individual line-pairs, according to

$$\sqrt{\frac{\Sigma d_P^2}{2 \times 30}}.$$

Each of these values was corrected by subtraction of a residual reading error contribution based on the normal triple reading procedure of the original work. These corrections are not strictly applicable to the simplified reading procedure, but since the two errors are not greatly different, and σ_{SC} is calculated as $\sqrt{\sigma_{TC}^2 - \sigma_{PC}^2}$ the inaccuracy is of no great practical importance. In some unpublished co-operative work which the authors have carried out with other laboratories no serious modification of comparative figures occurred even when no corrections for residual reading errors were included. The actual values used for reading error correction in the present work were in terms of variance 0·000441 and 0·000529 for σ_{TC}^2 and σ_{PC}^2 respectively.

Table I—INFLUENCE OF SOURCE PARAMETERS ON INTENSITY WITH METRO-VICKERS LOW-VOLTAGE CONTROLLED SOURCE
(Graphite auxiliary electrode and a 2½-mm. gap; Kodak *B*10 plate)

Unit	Setting			Exposure, sec.	Fe 2799·3 II, Fe 2793·9 II, Fe 2788·1 I					Cr 2870·4 II, Fe 2868·9 II			Cr 3021·6 I, Fe 3016·2 I			Cr 3408·8 II, Fe 3404·4 I			Mo 2816·1 II, Fe 2813·6 II		
					Densitometer Readings‡			Log I.R.§		Densitometer Readings		Log I.R.	Densitometer Readings		Log I.R.	Densitometer Readings		Log I.R.	Densitometer Readings		
	Ω	μH.	μF.		Fe 2799·3 II	Fe 2793·9 II	Fe 2788·1 I	Fe 2799·3 II / Fe 2793·9 II	Fe 2788·1 I / Fe 2793·9 II	Cr	Fe	Cr/Fe	Cr	Fe	Cr/Fe	Cr	Fe	Cr/Fe	Mo	Fe	Mo/Fe
H*			0·005	1 × 20	11·2	6·8	12·45	$\bar{1}$·912	$\bar{1}$·891	37·3	31·25	$\bar{1}$·932	40·05	42·85	0·047	25·8	32·05	0·077	28·35	30·55	0·023
M.V.†	6·3	15	11	2 × 20	24·4	15·1	11·05	$\bar{1}$·888	0·061	40·95	40·35	$\bar{1}$·991	32·65	38·6	0·073	33·35	22·4	$\bar{1}$·877	35·95	42·75	0·105
M.V.	12·5	15	11	4 × 20	36·9	27·95	11·2	$\bar{1}$·902	0·210	40·45	39·35	$\bar{1}$·941	40·15	42·85	0·094	41·4	33·8	$\bar{1}$·899	28·1	45·65	0·257
M.V.	2·5	15	11	6 × 20	38·15	28·5	6·1	$\bar{1}$·888	0·324	45·6	44·5	$\bar{1}$·971	34·6	41·1	0·101	42·1	28·75	$\bar{1}$·836	18·9	46·0	0·366
M.V.	6·3	15	5	4 × 20	17·6	10·65	8·35	$\bar{1}$·897	0·046	38·75	36·35	$\bar{1}$·965	41·15	43·45	0·049	30·3	17·9	$\bar{1}$·852	29·1	38·0	0·104
M.V.	6·3	15	2	8 × 20	22·95	13·85	9·7	$\bar{1}$·887	0·072	40·45	40·1	$\bar{1}$·959	33·1	38·95	0·043	40·8	32·2	$\bar{1}$·888	38·5	43·65	0·093
M.V.	6·3	60	11	2 × 20	24·6	15·35	9·05	$\bar{1}$·877	0·092	42·75	39·5	$\bar{1}$·945	28·75	32·2	0·038	34·05	12·5	$\bar{1}$·744	33·65	41·9	0·111
M.V.	6·3	100	11	2 × 20	24·4	14·9	9·5	$\bar{1}$·888	0·129	41·45	39·95	$\bar{1}$·980	26·3	31·75	0·052	31·8	11·8	$\bar{1}$·761	33·45	42·45	0·124
M.V.	6·3	250	11	3 × 20	25·25	15·75	7·0	$\bar{1}$·890	0·152	39·8	40·35	$\bar{1}$·930	25·85	33·2	0·042	31·65	8·1	$\bar{1}$·668	25·35	38·8	0·158

* Hilger high-voltage uncontrolled source, included for comparison
† Metro-Vickers controlled low-voltage unit
‡ Densitometer readings are given in terms of a clear-glass deflection of 50 cm.
§ Values are for the corresponding log-intensity ratios, deduced according to the authors' method of plate calibration

An alternative procedure for dealing with the complication from reading errors has been used by at least one other investigator (Geffner[8]). He treated the results by analysis of variance and obtained figures in very good agreement with the earlier work of one of the authors.[2] The present authors have retained here the original method, preserving direct continuity with the earlier work, which itself was designed for direct comparison with the results of Vincent and Sawyer.[9]

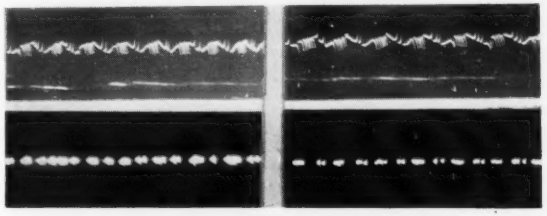
The term σ_P does not cover any large-scale plate variability of response, and σ_{SC} will contain any such contribution. The data given in Table XIV of the previous work[2] (p. 403) indicated that there was such a contribution, but that of those tested it was least for the Ilford Thin Film Half-Tone plates, and for these plates must be of such small order as to give rise to practical uncertainty of interpretation only with the very lowest values of σ_{SC}. Since, as will be seen later, the present work has largely been concerned with higher values, no serious complication is likely.

DETAILS OF TESTS

Preliminary study was made with the Metro-Vickers low-voltage unit to examine the effect of variation in circuit parameters on the low-voltage side, in relation to the time of exposure required to give suitable line-densities, and to explore the effect of these alterations on the resulting log-intensity ratios. The data given in Table I are derived from readings from a plate taken during the preliminary examination of the behaviour of the modified version of the unit. They include also comparison with the Hilger high-voltage unit. It will be noted that with the low-voltage unit, capacity was varied from 2 to 11 μF., inductance from the minimum 15 μH. to 250 μH., and resistance from 6·3 to 25 Ω. The 6·3 Ω resistance, which was the lowest addition available with this version of the unit, was necessary to prevent overheating of components.

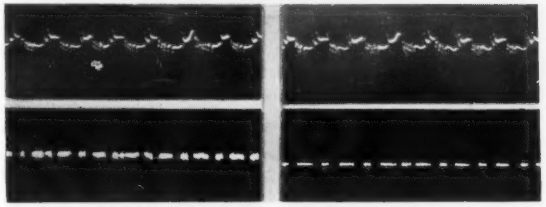
In addition to this study of data obtained from the resulting spectrograms, the effect of circuit variables on the constancy of the electrical charge-discharge conditions was examined by recording oscillograph voltage traces by a high-speed camera for both high- and low-voltage circuits of the Metro-Vickers unit, and for the single circuit of the Hilger unit. In both cases comparison pictures were also taken of the actual discharges. Oscillograms for various electrode systems, and including the use of a pointed corona discharge connected to the lower electrode, are given in Fig. 3. The corona wire which provided a steady discharge under occasionally difficult conditions with the low-voltage source, led to its general use with such units. The illustrations also show a transition from spark-like to arc-like discharge, by alteration of phasing with a suitable setting of circuit values in the Metro-Vickers unit.

Figure 3 shows the steadiness of the Metro-Vickers unit voltage traces, in contrast to the fluctuations evident in discharge form and intensity from the corresponding discharge pictures. Thus, although the voltage trace stability was obvious, compared with the erratic behaviour of the simple high-voltage



(a) No corona wire (b) With corona wire

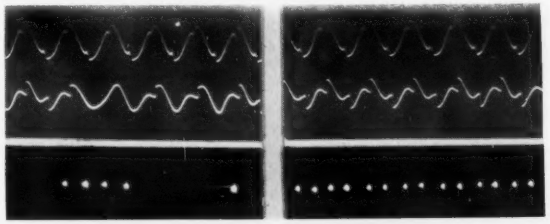
(a) and (b) Pointed silver-flat steel electrodes



(c) No corona wire (d) With corona wire

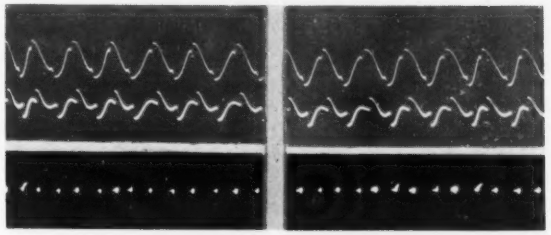
(c) and (d) Pointed graphite auxiliary electrodes

Fig. 3 (a) to (d)—Hilger high-voltage unit (0·00 5μF.)



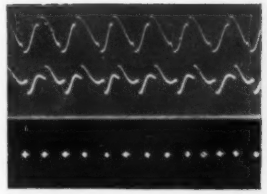
(e) No corona wire (f) With corona wire

(e) and (f) Pointed silver-flat steel electrodes



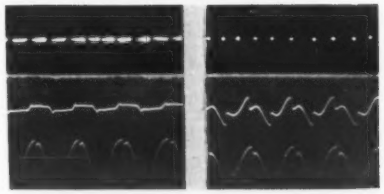
(g) No corona wire (h) With corona wire

(g) and (h) Pointed graphite auxiliary electrodes



(i) With corona wire using two pointed steel pencil electrodes

Fig. 3 (e) to (i)—Metro-Vickers low-voltage controlled unit (5·6Ω, 15μH., 10μF.)



(j) With phase adjusted to spark-type discharge (k) With phase adjusted to arc-type discharge

Fig. 3 (j) and (k)—Metro-Vickers low-voltage controlled unit (90Ω,500μH., 10μF.). Pointed silver-flat steel electrodes with corona wire

Fig. 3—Typical oscillograms (top) and high-speed camera discharges (bottom). Time progresses from left to right

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Table II

RESULTS FOR σ_{SC} WITH METRO-VICKERS CONTROLLED LOW-VOLTAGE UNITS

Unit	Original																Modified	
Electrode System	Pointed Steel Pencils		Pointed Silver-Flat Steel						Pointed Graphite-Flat Steel									
Type of Plate	Kodak *B5*								Ilford Thin-Film Half-Tone									
Plate No.	1	2	3	4	5	6	7	8	9	10	11	12, 13, 14	15, 16, 17	18	19	20	21, 22, 23	24
Source Setting Ω μH. μF.	5·6 15 10	5·6 15 10	5·6 15 10	5·6 15 10	5·6 15 10	5·6 15 10	0 15 10	11 15 10	5·6 15 10	5·6 15 10	5·6 15 10	5·6 15 10	5·6 15 10	0 15 10	0 15 10	11 15 10	6·3 15 11	6·3 100 11
Gap Width, mm.	2·5	2·5	4	1·25	2·5	2·5	2·5	2·5	4	1·25	1·25	2·5	2·5	2·5	2·5	2·5	2·5	2·5
Air Blast*	...	Yes	...	...	...	Yes	...	...	...	...	Yes	...	Yes	...	Yes	...	...	...
Intensity Ratio for $\frac{\text{Fe II 2793·9}}{\text{Fe I 2788·1}}$	0·76	0·83	0·57	0·77	0·59	0·74	0·97	0·45	0·68	0·98	1·21	0·85	0·85	1·25	1·33	0·63	0·90	0·74
$\frac{\text{Fe 2799·3 II (1/100)}}{\text{Fe 2793·9 II (8/150)}}$	0·0031	0·0045	0·0087	0·0083	0·0044	0·0047	0·0052	0·0068	0·0046	0·0035	0·0041	0·0038 0·0039 0·0039 } 0·0039	0·0042 0·0022 0·0045 } 0·0038	0·0041	0·0040	0·0052	0·0019 0·0024 0·0016 } 0·0020	0·0030
$\frac{\text{Fe 2788·1 I (150/150)}}{\text{Fe 2793·9 II (8/150)}}$	0·0240	0·0298	0·0219	0·0197	0·0290	0·0170	0·0215	0·0197	0·0161	0·0078	0·0095	0·0069 0·0079 0·0121 } 0·0092	0·0133 0·0111 0·0101 } 0·0116	0·0100	0·0138	0·0179	0·0029 0·0045 0·0044 } 0·0040	0·0052
$\frac{\text{Cr 2870·4 II (25/300)}}{\text{Fe 2868·9 II (80/40)}}$ Fe 2868·5 (5/40)	0·0064	0·0058	0·0131	0·0093	0·0073	0·0087	0·0075	0·0063	0·0083	0·0040	0·0034	0·0035 0·0023 0·0038 } 0·0033	0·0038 0·0029 0·0038 } 0·0035	0·0049	0·0044	0·0062	0·0028 0·0023 0·0026 } 0·0026	0·0024
$\frac{\text{Cr 3021·6 I (300/200)}}{\text{Fe 3016·2 I (200/150)}}$	0·0074	0·0062	0·0086	0·0114	0·0055	0·0100	0·0120	0·0126	0·0063	0·0039	0·0028	0·0049 0·0050 0·0053 } 0·0051	0·0041 0·0023 0·0034 } 0·0033	0·0063	0·0064	0·0088	0·0036 0·0062 0·0027 } 0·0044	0·0023
$\frac{\text{Cr 3408·8 II (35/100)}}{\text{Fe 3404·4 I (100/150)}}$	0·0212	0·0206	0·0172	0·0201	0·0311	0·0153	0·0333	0·0175	0·0197	0·0164	0·0134	0·0085 0·0126 0·0113 } 0·0109	0·0140 0·0155 0·0086 } 0·0130	0·0185	0·0154	0·0195	0·0051 0·0065 0·0056 } 0·0058	0·0101
$\frac{\text{Mo 2816·1 II (200/300)}}{\text{Fe 2813·6 II (5/60)}}$	0·0190	0·0145	0·0206	0·0144	0·0162	0·0190	0·0208	0·0151	0·0158	0·0101	0·0071	0·0182 0·0147 0·0211 } 0·0183	0·0136 0·0093 0·0107 } 0·0113	0·0176	0·0142	0·0198	0·0030 0·0067 0·0076 } 0·0061	0·0113

* Twin jets at 180° with 4·8-mm. orifices, 20 mm. from spark. Flow 1¼ cu. ft./min. at pressure of 6 cm. of mercury
Figures in brackets give the arc/spark intensities according to the M.I.T. Tables

Table III

INFLUENCE OF ELECTRODE SYSTEM AND AIR BLAST ON RESULTS FOR σ_{SC} WITH HILGER HIGH-VOLTAGE SOURCE*

Electrode System	Pointed Steel Pencils		Pointed Silver-Flat Steel		Pointed Graphite-Flat Steel			
Plate No.	25	26	27	28	29	30	31, 32, 33‡	34
Gap width, mm.	2·5	2·5	2·5	2·5	4	1·25	2·5	2·5
Air blast†	...	Yes	...	Yes	...	...	...	Yes
Fe II 2793·9 / Fe I 2788·1	1·35	1·40	1·26	1·34	1·12	1·27	1·22	1·26
Fe 2799·3 II / Fe 2793·9 II	0·0044	0·0027	0·0037	0·0038	0·0040	0·0044	0·0020	0·0031
Fe 2788·1 I / Fe 2793·9 II	0·0052	0·0034	0·0064	0·0045	0·0099	0·0051	0·0030	0·0043
Cr 2870·4 II / Fe 2868·9 II Fe 2868·5	0·0047	0·0025	0·0039	0·0036	0·0038	0·0031	0·0021	0·0026
Cr 3021·6 I / Fe 3016·2 I	0·0064	0·0039	0·0048	0·0048	0·0039	0·0045	0·0023	0·0030
Cr 3408·8 II / Fe 3404·4 I	0·0063	0·0067	0·0047	0·0056	0·0057	0·0044	0·0039	0·0031
Mo 2816·1 II / Fe 2813·6 II	0·0050	0·0046	0·0041	0·0031	0·0028	0·0022	0·0026	0·0034

* Using 0·005 μF. and no added resistance or inductance ; Ilford Thin-Film Half-Tone Plates used throughout
† Twin jets at 180° with 4·8-mm. orifices, 20 mm. from spark. Flow 1¼ cu. ft./min. at pressure of 6 cm. of mercury
‡ Mean results (see Table IV for details)

source with its variable 1–6 discharges per half cycle, this did not necessarily imply a corresponding improvement in stability of the resulting spectral output.

Table II gives the main series of values obtained from the Metro-Vickers unit for σ_{SC}, in terms of log-intensity ratio. It covers a study of the three electrode combinations, the variation in discharge gap width, and the effect of air blast in the gap. Capacity in the low-voltage circuit was kept at the maximum 10–11 μF. throughout because reduction produced a serious increase in exposure with no apparent effect on response as judged by log-intensity ratio (*see* Table I). Resistance changes in this circuit produced a considerable effect, both on log-intensity ratios and on exposure times required, and their influence was studied by tests over the range 0–11 Ω (*see* Table II). Variation of inductance produced much smaller effects on log ratio and exposure ; the tests described in this paper were limited to a single comparison between the 15 and 100 μH. levels.

Values for the average intensity ratio for each plate of the line-pair Fe (II) 2793·9 – Fe (I) 2788·1 are included in Table II and indicate the change in character of the discharge with the varying conditions, lower values indicating movement towards a more arc-like character.

Results obtained in a series of comparison tests with the Hilger high-voltage uncontrolled unit, including variation in electrode system and gap width, and the effect of air blast, but with no change in circuit parameters, are given in Table III.

The effect of the 15-sec. pre-spark was studied for both units. The results are given in Table IV, which includes data on the effect of exposure time, a four to one ratio being achieved by movement of the electrodes relative to the slit from the normal 38 cm. to 20 cm. The Metro-Vickers high-voltage arrangement was also included in this latter series.

Where plates covering a particular set of conditions were taken in duplicate or triplicate, the results for σ_{SC} sometimes showed a very considerable scatter, *e.g.*, results for the low-voltage source (*see* Table IV). Since such scatter might have been caused by the incidence of a few abnormally divergent results, attributable to the occasional influence of factors not included in the random variation of the main series, a study was made of the error distribution in certain selected cases. This distribution was compared with the Gaussian distribution calculated from the standard deviation by means of the values given in Table 9 of British Standards Publication B.S. 600*R*.[10] The standard deviation σ_{SC} was not suitable for this study since it was deduced from the difference between two variances and not directly from a series of deviations. The standard deviation σ_T corresponding to total variation of the log ratios about the mean was used. The resulting figures are compared in Table V. They cover the iron-line pair from plate 40, which was chosen as being unexpectedly high, and four other cases comparing widely different values in repetition plates. These distribution figures show that the deviations, even in these extreme cases, are in reasonable approximation to random distribution, and that the high values have not resulted from the

Table IV

EFFECT OF PRE-SPARK AND LENGTH OF EXPOSURE ON σ_{SC} WITH HILGER AND METRO-VICKERS UNITS*

Source	Hilger High-Voltage			Metro-Vickers High-Voltage		Metro-Vickers Low-Voltage (modified)		
Setting { Ω / μH. / μF.	... / ... / 0·005			... / ... / 0·034		6·3 / 15 / 11		
Source—Slit, cm.	38	38	20	38	20	38	38	20
Pre-spark, sec.	15	0	15	15	15	15	0	15
Exposure, sec.	2 × 60	2 × 60	2 × 15	2 × 120	2 × 30	2 × {150, 150, 105}	2 × {105, 120}	2 × 45
Plates No.	31, 32, 33	35, 36	37	38	39	21, 22, 23	40, 41	42, 43
Fe II 2793·9 / Fe I 2788·1	1·22	1·24	1·23	1·02	1·08	0·90	0·87	0·94
Fe 2799·3 II / Fe 2793·9 II	0·0017, 0·0021, 0·0021 } 0·0020	0·0019, 0·0018 } 0·0019	0·0020	0·0024	0·0027	0·0019, 0·0024, 0·0016 } 0·0020	0·0018, 0·0019 } 0·0019	0·0016, 0·0016 } 0·0016
Fe 2788·1 I / Fe 2793·9 II	0·0026, 0·0035, 0·0027 } 0·0030	0·0026, 0·0033 } 0·0030	0·0040	0·0053	0·0048	0·0029, 0·0045, 0·0044 } 0·0040	0·0080, 0·0079 } 0·0080	0·0033, 0·0040 } 0·0037
Cr 2870·4 II / Fe 2868·9 II / Fe 2868·5	0·0024, 0·0021, 0·0017 } 0·0021	0·0026, 0·0021 } 0·0024	0·0021	0·0041	0·0043	0·0028, 0·0023, 0·0026 } 0·0026	0·0023, 0·0021 } 0·0022	0·0030, 0·0017 } 0·0024
Cr 3021·6 I / Fe 3016·2 I	0·0027, 0·0024, 0·0018 } 0·0023	0·0031, 0·0038 } 0·0035	...	0·0058	0·0051	0·0036, 0·0062, 0·0027 } 0·0044	0·0038, 0·0033 } 0·0036	0·0035, 0·0067 } 0·0044
Cr 3408·8 II / Fe 3404·4 I	0·0024, 0·0044, 0·0046 } 0·0039	0·0031, 0·0028 } 0·0030	0·0031	0·0048	0·0057	0·0051, 0·0065, 0·0056 } 0·0058	0·0045, 0·0044 } 0·0045	0·0037, 0·0036 } 0·0037
Mo 2816·1 II / Fe 2813·6 II	0·0029, 0·0029, 0·0018 } 0·0026	0·0029, 0·0017 } 0·0024	0·0034	0·0031	0·0040	0·0030, 0·0067, 0·0076 } 0·0061	0·0108, 0·0105 } 0·0106	0·0033, 0·0087 } 0·0066

* Using graphite auxiliary electrode, 2½-mm. gap, and Ilford Thin-Film Half-tone Plates

occasional intrusion of interfering factors of overriding importance.

In Table VI results are collected comparing the various units tested, including the Hilger uncontrolled high-voltage unit, the Metro-Vickers controlled high-voltage unit, the two Metro-Vickers controlled low-voltage units, the Multisource, and B.N.F. controlled low-voltage units. The Metro-Vickers low-voltage figures are given for the conditions adopted by the authors as the best all-round standard working conditions based on the earlier comparisons. The Multisource unit was operated under similar conditions for direct comparison, and also at a setting based on that suggested for steel by Hasler and Kemp.[5] The B.N.F. unit was operated at high capacity with the lowest resistance for stability of discharge, to obtain the shortest possible exposure. Variation in sample polarity was made with these two unidirectional discharge units.

DISCUSSION OF RESULTS

Influence of Circuit Parameters with Metro-Vickers Low-Voltage Unit

The results detailed in Table I bring out a number of interesting features in relation to the effect of circuit parameters on the response of the Metro-Vickers low-voltage unit.

The alteration of C_1 and R_1 (Fig. 1) has a major influence on exposure : increase of capacity and decrease of resistance lead to approximately proportional increases in intensity. Thus, other things being equal, the highest available capacity and lowest resistance permissible are to be preferred. The effect of inductance (L_1) on intensity was much less marked ; an increase from 15 to 100 μH. produced very little effect and a further increase to 250 μH. was covered by a 50% increase in exposure.

The influence of these factors on relative intensity is indicated by the log-intensity-ratio values. The matched iron-line pair and the two matched chromium–iron pairs showed very satisfactory steadiness with no marked trends. Even the values given by the Hilger high-voltage unit showed relatively slight shift. The unmatched irons and chromium–iron pair, however, showed very considerable changes with variation in resistance and inductance. There was also a considerable variation between the two types of unit. In this respect, the molybdenum–iron pair, in spite of its (II)/(II) classification by Harrison,[7]

Table V

DISTRIBUTION OF VARIATION COMPARED WITH GAUSSIAN IN RESPECT OF σ_T*

Plate No.	40		42		43		42		43	
Line-Pair	Fe 2788·1 I / Fe 2793·9 II		Cr 3021·6 I / Fe 3016·2 I		Cr 3021·6 I / Fe 3016·2 I		Mo 2816·1 II / Fe 2813·6 II		Mo 2816·1 II / Fe 2813·6 II	
σ_T	0·0084		0·0043		0·0075		0·0040		0·0092	
Number Exceeding Deviation Limits	Gaussian	Actual	Gaussian	Actual	Gaussian	Actual	Gaussian	Actual	Gaussian	Actual
0·0015	...	...	44	45	...	...	44	43	...	...
0·0025	46	46	34	37	44	46	32	31	...	...
0·0035	...	...	25	24	...	...	23	21	42	46
0·0045	35	34	17	18	33	36	16	15	...	...
0·0055	...	...	...	...	...	...	...	...	...	...
0·0065	...	...	8	6	22	24	6	8	34	30
0·0075	22	22	...	...	...	...	...	...	...	...
0·0085	...	...	...	...	...	...	2	1	...	...
0·0095	...	...	1·7	2	12	10	...	...	18	19
0·0105	13	15	...	...	...	...	...	...	...	...
0·0125	...	...	...	...	6	6	...	...	10	12
0·0145	5	4	...	...	...	...	...	...	...	...
0·0155	...	...	...	...	2	2	...	...	6	7
0·0185	1·7	1	...	...	...	...	...	...	3	2

* Standard deviation corresponding to the total variation of the 60 readings from their mean

behaved as an unmatched pair, which is in line with its general variability of response as recorded in the later tables. The Cr (II)–Fe (I) pair was most affected by inductance, but the Fe (II)–Fe (I) pair and the molybdenum–iron pair showed the biggest changes with resistance.

These various combinations for the low-voltage source showed steady high- and low-voltage traces on the monitoring oscilloscope (Fig. 3). This also appeared to apply to the 0 Ω, 15 μH., 10 μF. setting of the original unit, although this setting gave occasional instability.

Main Series of Tests with Metro-Vickers Low-Voltage Units

The main series of results for σ_{SC} with the Metro-Vickers low-voltage units are summarized in Table II. The results indicate no improvement with lower or higher resistance than the 6 Ω setting, which is desirable in any case to ensure electrical stability, nor with inductance increased above the 15 μH. residual level. The standard setting adopted for study of other variables was, therefore, chosen at these minimum working values to give the maximum available intensities.

Gap variation from the normal 2½ mm. to 1¼ mm. gave no improvement, and an increase to 4 mm. gave notably inferior results for the steadier line-pairs.

Air blast across the gap had little, if any, effect with no indication of any consistent improvement. There is an indication that the graphite auxiliary electrode is superior but there is little to choose between the other two combinations.

On the basis of all these results, the standard conditions selected for comparison of this type of unit with other sources include the graphite auxiliary electrode set for 2½-mm. gap, and operated at the 5·6–6·3 Ω, 15 μH., 10–11 μF. setting, without air blast.

The general character of the discharge, according to the operating conditions, may be seen from the intensity-ratio figures for the Fe (II)–Fe (I) pair given in Table II. The rise in this figure, indicating a more spark-like discharge, is favoured by a decrease in resistance and inductance, by the use of the graphite auxiliary electrode, by air blast, and by increasing gap width. The standard conditions selected above correspond to an intermediate value of the intensity ratio.

Results given in Table IV suggest that neither the effect of the 15-sec. pre-spark nor the length of exposure is of importance for the satisfactorily matched line-pairs. In the absence of pre-sparking, there was a considerable rise in the values of σ_{SC} for the unmatched iron and the molybdenum–iron pairs, while decrease of exposure time from 100–150 sec. to 45 sec. was accompanied by lower values for σ_{SC} for the unmatched chromium–iron pair. Otherwise there was little or no effect.

Superior results have been obtained (Table IV) with the Metro-Vickers unit after modification and component renewal, the later version giving considerably lower results for σ_{SC} in many cases. Detailed examination of the reasons for this was outside the scope of the present investigation, but the result suggests there may well be scope for some further improvement in the behaviour of this type of unit.

Tests with the Hilger High-Voltage Unit

The results with this unit are summarized in Tables III and IV. The 2·5-mm. gap again gave results considerably superior to those with the 4-mm. gap, and in most cases to those with the 1¼-mm. gap. There was probably little to choose between the double steel pencils or the silver auxiliary electrode, but some general lowering of the variability occurred with the graphite auxiliary electrode. The use of air blast may have effected some improvement with the

Table VI

COMPARISON OF VALUES OF σ_{SC} FOR VARIOUS SOURCES AT SELECTED SETTINGS*

Type of Unit	High-Voltage Condensed Spark			Low-Voltage Controlled Sources					
	Hilger Uncontrolled Unit	Metro-Vickers Controlled Unit		Metro-Vickers (Original)	Metro-Vickers (Modified)	Multisource		B.N.F.M.R.A. General Purpose Source	
Setting Ω	...	...	...	5·6	6·3	5·4	10·4	2	2
Setting μH.	...	...	...	15	15	25	175	0·06	0·06
Setting μF.	0·005	0·0085	0·034	10	11	10	4	20	20
Setting Polarity	...	...	...	...	...	Negative	Positive	Negative	Positive
Exposure, sec.	2 × 60	2 × 120	2 × 120	2 × 120	2 × (105–150)	2 × 210	2 × 360	2 × 300	2 × 300
Plate No.	31, 32, 33†	44‡	38	12, 13, 14†	21, 22, 23†	45	46	47	48
Fe II 2793·9 / Fe I 2788·1	1·22	0·96	1·02	0·85	0·90	1·24	0·89	0·79	1·13
Fe 2799·3 II / Fe 2793·9 II	0·0020	0·0038	0·0024	0·0039	0·0020	0·0034	0·0035	0·0022	0·0026
Fe 2788·1 I / Fe 2793·9 II	0·0030	0·0085	0·0053	0·0092	0·0040	0·0106	0·0041	0·0064	0·0068
Cr 2870·4 II§ / Fe 2868·9 II Fe 2868·5	0·0021	0·0040	0·0041	0·0033	0·0026	0·0044	0·0039	0·0054	0·0048
Cr 3021·6 I / Fe 3016·2 I	0·0023	...	0·0058	0·0051	0·0044	0·0033	0·0032	0·0035	0·0029
Cr 3408·8 II / Fe 3404·4 I	0·0039	0·0096	0·0048	0·0109	0·0058	0·0115	0·0137	0·0165	0·0174
Mo 2816·1 II / Fe 2813·6 II	0·0026	0·0040	0·0031	0·0183	0·0061	0·0039	0·0104	0·0100	0·0063

* Using graphite auxiliary electrode, 2½ mm. spark gap, 15-sec. pre-spark and Ilford Thin-Film Half-Tone plates
† Mean results (see Tables II and IV for details)
‡ Distance from source to slit for this plate was 20 cm. as against 38 cm. for the others, thereby considerably shortening the exposure
§ To give an indication of the practical significance of these values of σ_{SC}, for this line-pair conversion to percentage chromium necessitates multiplication by a factor of 455 (ref. 2, p. 405)

steel pencils, but not with the other two electrode systems.

The standard conditions selected for comparison with other units consisted of the pointed graphite to flat steel electrode combination with a 2·5-mm. gap and no air blast. The intensity-ratio values for the unmatched iron lines had an intermediate value for this set of conditions, although this source gives considerably more spark-like discharges than those obtained with the Metro-Vickers low-voltage unit with the authors' selected circuit parameters.

Presence or absence of the 15-sec. pre-spark appeared of no significance with this unit, and reduction of exposure time had no important effect.

Tests with Metro-Vickers High-Voltage Unit

As the two plates taken with this unit, using the highest capacity setting of 0·034 μF., covered also variation in exposure, they have been included in Table IV. Variation of exposure time had no apparent effect. Results were consistently inferior to those given by the Hilger uncontrolled unit, and the unmatched iron-line intensity-ratio figures indicate rather more arc-like conditions than in the Hilger unit.

The results in Table VI for the low-capacity setting (0·085 μF.) are generally inferior to the higher power setting. In addition, the much lower intensity is reflected in the use of the same exposure as for the higher capacity, but at only half the distance from the slit.

Comparison of Various Units

In Table VI the results are collected for the various units operating under the standard conditions selected for comparison, as already discussed. In addition, results are given from the four plates representing the Multisource and B.N.F. controlled low-voltage units. These four plates represent a limited and arbitrary choice of conditions but it is considered that the results provide a comparison of real value and importance. The 15-sec. pre-spark period has been used in the test with both these sources.

The Multisource plates, as already indicated, were taken under conditions approximating, in the one case to those adopted by the present authors as standard for the Metro-Vickers low-voltage unit, and in the other to those recommended by Hasler and Kemp.[5] There are some curious differences and unexpectedly high results in these two sets, but in general the results show a similarity to those with the Metro-Vickers low-voltage units, and in no case are they as good as those obtained with the Hilger high-voltage unit.

The B.N.F. source circuit setting was chosen, as explained earlier, to provide the highest intensity consistent with general electrical stability. It showed promisingly low values of σ_{SC} for the matched iron lines and for the Cr (I)–Fe (I) pair, but the results were not so good as with the Hilger unit. With the

other line-pairs the discrepancy is much more marked.

Relative Behaviour of Different Line-Pairs

The behaviour of different line-pairs may be conveniently studied from Table VI : under suitable conditions, the low-voltage units approach the Hilger unit low values of σ_{SC} for matched line-pairs, but the poorer results for unmatched pairs tend to be much exaggerated with the controlled sources. The molybdenum–iron pair, although giving low results with the Hilger unit, consistent with its (II)/(II) Harrison classification, shows great variability with the low-voltage units. Both this pair and the unmatched iron–iron and chromium–iron pairs show extremely high values for σ_{SC} with some of the less favourable low-voltage unit settings given in Table II.

CONCLUSIONS

The investigation has provided data permitting the selection of operating conditions that give maximum reproducibility within the range of conditions covered. This selection includes the use of a graphite auxiliary electrode in preference to silver or double steel pencils, and the use of a 2·5-mm. gap in preference to a 1·25- or 4-mm. gap. The use of an air blast across the gap does not appear to have any particular value.

The use of a 15-sec. pre-spark may have some value for unmatched line-pairs with the Metro-Vickers low-voltage unit, but gives no general improvement. It was included in the source comparison work as unlikely to contribute anything undesirable, but as having a possibly beneficial effect in some cases.

From the study of the behaviour of the Metro-Vickers low-voltage controlled source units, the best all-round conditions selected are those with maximum capacity, minimum inductance, and the smallest available addition of resistance to give satisfactory electrical behaviour. This corresponded to 10–11 μF., 15 μH., and 5·6–6·3 Ω for the two units. With this setting the original unit behaved differently from the superior modified version. In principle the circuit remained unchanged and the improvement was presumably largely brought about by the replacement and modification of certain components, notably the choke L_2 and the high-voltage transformer T_1. Modified wiring, including provision of more earthing points, may have had some influence. The present investigation, however, has been limited to a study of the various sources and has not included any deliberate examination of the effect of component and circuit modifications, except in regard to those components intentionally provided in variable form. It may be noted that the selected optimum setting of these latter does not correspond to the most spark-like or arc-like conditions tested, but is intermediate in this respect.

The most important result from this investigation is the comparison of the different units. The various controlled units show no superiority over the simple uncontrolled high-voltage condensed-spark Hilger unit. In fact this latter has shown an overall superiority throughout, which is approached by the controlled units only under the best operating conditions and only for certain line-pairs. With line-pairs made up from lines of different classification, the controlled low-voltage units are liable to give very inferior results, in spite of the variable number of discharges per half cycle from the Hilger unit. It is evident that the electrical control imposed has not been accompanied by a corresponding control of the discharge ; this is in line with the pictorial record in Fig. 3, which shows distinct fluctuations in form and direction of the discharge in spite of the stability of voltage oscillograms.

A further point of practical importance in favour of the uncontrolled, high-voltage unit is the lower exposure time required. This is about half that for the Metro-Vickers low-voltage, controlled source. The Multisource unit and the B.N.F. unit both give only one discharge per cycle, as against the two from the Metro-Vickers unit, and require still longer exposures. The plates for Multisource and B.N.F. units were taken in a different laboratory from the main series, and the relative exposures may not be strictly comparable, but the figures suggest about four times the Hilger unit exposure for the Multisource under conditions approximating to the Metro-Vickers optimum, and six times that for the Hilger unit under the Hasler and Kemp setting. The B.N.F. source was intermediate.

Acknowledgments

The authors wish to acknowledge the courtesy and assistance of Messrs. Metropolitan Vickers Electrical Co., and of the Director of the British Non-Ferrous Metals Research Association, in making available the controlled source units tested. They also wish to thank Dr. C. Sykes, F.R.S., Technical Director of Messrs. Thos. Firth and John Brown, Ltd., for his continued interest and encouragement in the work, and the Directors of the Company for permission to publish the results.

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Distribution of Materials in the Blast-Furnace

Part III — FURTHER FACTORS INFLUENCING THE DISTRIBUTION OF SOLIDS IN THE BLAST-FURNACE

By R. Wild, Ph.D.

SYNOPSIS

Previous studies on the distribution of materials in the blast-furnace are extended to further consideration of the effects of modifications in (1) design and operation of the head-gear and (2) the nature of the materials charged. Conclusions drawn from the investigation are enumerated.

In previous papers of the present series[1,2] the effect of various modifications of the furnace head-gear and operation on the stockline contour and the segregation of materials has been considered, together with methods of obtaining improvements in the distribution by means of compensated charging. These investigations were carried out using small-scale models of various types, and the results were subsequently confirmed on the larger scale of the experimental blast-furnace.[2] In this paper further consideration is given to the effects of modifications in the design and operation of the head-gear and the nature of the materials charged upon the distribution of solid materials in the blast-furnace, using the model technique already described.

It was concluded from the work described in Part I that one of the most important factors controlling this distribution is the stockline contour which, as was shown in that work, is governed by the trajectory of the falling solids and the height of the stock. The effect of the latter is readily envisaged, and has been adequately summarized in the conclusion to Part I. The former is dependent upon a number of factors which are enumerated below and which will be dealt with at some length because of their importance, having special regard to those aspects not previously considered. In some cases it is difficult to separate the influence of a particular variable upon the trajectory from its influence upon the movement of the material after striking the stockline, and in these instances the combined effect will be considered.

FACTORS INFLUENCING TRAJECTORY OF FALLING MATERIAL

The factors influencing the trajectory of material falling from the bell during the charging operation may be summarized as (1) the design of the bell and hopper, (2) the movement of the bell, and (3) the nature of the materials charged, various sub-factors being grouped together under each of the items mentioned.

DESIGN OF THE BELL AND HOPPER

Apex Angle of the Bell

In Part I[1] it was noted that the apex angle of the bell had very little effect upon the trajectory of the falling material. This observation may be explained by the fact that whilst the velocity of the material leaving the bell increases with diminishing apex angle, this is balanced by the decreased horizontal component of this velocity.

Extent of Bell Overhang

Variation in the extent of the overhang of the bell, which is defined as the vertical distance between the plane of the bell rim and the inner sealing position of the bell, will cause the velocity of the material as it leaves the bell to vary, with a consequent alteration in the trajectory. In order to investigate this effect a series of experiments with varying bell overhang was carried out in a slice model of the normal type, care being taken to keep the quantities charged and the manner of charging the same in each case. The trajectories were recorded photographically, and results obtained with closely graded material (20–40-mesh porcelain) and bell overhangs of 0·015 in., 0·08 in., and 0·14 in. are shown in Figs. 1, 2, and 3 respectively; from these photographs the mean stream paths have been calculated, and are shown plotted against the distance below the open bell (Fig. 34). A definite small variation in the initial mean stream path, while not immediately apparent in Figs. 1 to 3, can be seen from the curves in Fig. 34, the fall growing more vertical as the overhang decreases and the point of inflection, by rebound from the walls, of the mean stream path changing from about 1·1 in. to about 1·5 in. below the closed bell as the overhang decreases from 0·14 in. to 0·015 in. This is undoubtedly due to the increased velocity gained by sliding down a greater length of bell surface giving a greater throw to the walls.

The distribution of coarse (10–20-mesh) and fine (40–60-mesh) limestone was found, using the same head-gear and a stockline height of approximately 1½ in. below the closed-bell rim, the bell drop being ⅜ in. The model was initially two-thirds filled with a neutral material, floating on mercury in the well below the "hearth." The mixed material was charged

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Dr. Wild is at the Blast-Furnace Research Laboratory of the Imperial College of Science and Technology, South Kensington.

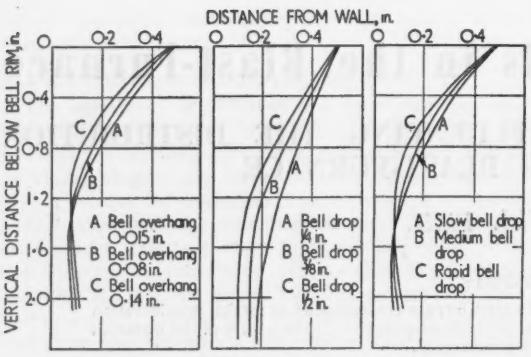


Fig. 34 *Fig. 35* *Fig. 36*

Fig. 34—Mean stream paths of closely graded material charged from bells of 0·015 in., 0·08 in., and 0·14 in. overhang, respectively (*see also* Figs. 1 to 3)

Fig. 35—Mean stream paths obtained with bell drops of ¼ in., ⅜ in., and ½ in. respectively. Bell/throat ratio 0·64 (*see also* Figs. 7 to 9)

Fig. 36—Mean stream paths obtained with bell-lowering rates of 5 sec., 2 sec., and very rapid dumping (*see also* Figs. 10 to 12)

until the desired stockline was reached, when withdrawal of mercury from the base was commenced, the stockline being kept at a constant level by charging. Figures 4, 5, and 6 show the distributions obtained by this means with bell overhangs of 0·015 in., 0·08 in., and 0·14 in. respectively. Whilst in general the stockline contour and the segregation pattern are the same in each case, it can be seen that there is (i) a perceptible flattening of the stockline contour at the walls where the overhang is smallest (Fig. 4), owing to the more vertical fall of the charged material (*see* Fig. 34), and (ii) a noticeable increase of coarse material in the wall region consequent upon this contour. The distributions of coarse material in the two extreme experiments were calculated from Figs. 4 and 6 by particle counts, and are shown in Fig. 38.

Relative Size of Bell

The effect of the bell/throat ratio has been discussed in Part I.[1] Here not only is there diminished discharge velocity with decreasing bell size, with consequent alteration of the trajectory of the falling material, but also, and more important, an increased horizontal distance to be covered to any given annular position at or near the walls. Both these effects work in the same direction, and together produce the segregation effects associated with a small bell/throat ratio.

MOVEMENT OF BELL

From the point of view of normal practice there are two factors to be considered in regard to the mode of lowering the bell, namely (*a*) the extent of the bell drop and (*b*) the rate of lowering the bell. In Part II[2] the effect of a third factor, *viz*, the raising of a bell constructed such that its diameter was slightly less than that of the hopper, was examined, and the application of a bell of this type in a compensated charging cycle was worked out.

Extent of Bell Drop

Increasing the extent of the bell drop will allow the material in the hopper to leave the bell at a greater velocity, with a consequent increase in the throw to the walls. This effect may be seen in Figs. 7, 8, and 9, where trajectories of material dumped from a bell of bell/throat ratio 0·64 are shown with bell drops of ¼ in., ⅜ in., and ½ in., respectively. The mean stream paths obtained from Figs. 7 to 9 are shown in Fig. 35.

In Part I[1] the effect of alterations in the bell drop were recorded, but in these experiments the falling stream of material was deflected inwards by plates fixed to the wall below the bell rim. Under these conditions the limiting factor is the extent of the gap between the bell rim and the deflecting plate, this decreasing as the bell drop increases, and the streams are thus deflected further towards the centre when the bell drop is smallest, in spite of the decreased velocity off the bell.

Rate of Lowering Bell

In order to study the effect of rate of bell lowering, the head-gear of a standard slice model was modified in the manner shown in Fig. 37. The bell (*B*) was supported by a lever (*L*) counterbalanced so that the bell was normally in the closed position. The other end of the lever was connected to a plunger (*P*) floating on mercury contained in the tube (*T*). The bell could thus be opened at any desired rate by raising the mercury in the tube at a suitable speed by manipulation of the reservoir (*R*). The trajectories of falling 20–40-mesh porcelain were first recorded for different dumping speeds of the bell, the desired speeds being obtained by a suitable adjustment of the rate of entry of mercury into the tube; the trajectories with dumping times of 5 sec, 2 sec., and very rapid dumping are shown in Figs. 10, 11, and 12. Whilst the stream paths are not very different, it is possible to see that slower lowering of the bell gives a rather more vertical fall of material. This can be

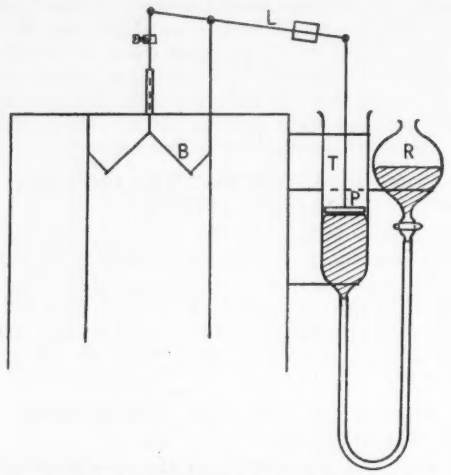


Fig. 37—Apparatus for control of bell-lowering rate. The bell *B* is closed by a counterbalanced lever *L* connected to a plunger *P* floating on mercury in a tube *T*. The bell speed is controlled by movement of the reservoir *R*

Fig. 1—Bell overhang 0·015 in. Fig. 2—Bell overhang 0·08 in. Fig. 3—Bell overhang 0·14 in.

Figs. 1 to 3—Trajectories of closely graded material

Fig. 4—Bell overhang 0·015 in. Fig. 5—Bell overhang 0·08 in. Fig. 6—Bell overhang 0·14 in.

Figs. 4 to 6—Distributions obtained on charging mixed material with varying bell overhang

Fig. 7—Bell drop $\frac{1}{4}$ in.

Fig. 8—Bell drop $\frac{3}{8}$ in.

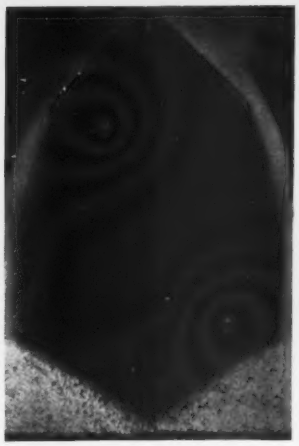


Fig. 9—Bell drop $\frac{1}{2}$ in.

Figs. 7 to 9—Influence of bell drop on trajectories. The throw of material to the walls increases with increasing bell drop, owing to greater velocities. Bell/throat ratio 0·64

Fig. 10—Dumping time 5 sec.

Fig. 11—Dumping time 2 sec.

Fig. 12—Very rapid dumping

Figs. 10 to 12—Effect of dumping time on trajectories. Slower lowering of bell gives rather more vertical fall of material

Fig. 13—Dumping time 5 sec. Fig. 14—Dumping time 2 sec. Fig. 15—Very rapid dumping

Figs. 13 to 15—Distribution obtained on charging mixed materials at various dumping rates

Fig. 16—Size segregation of very widely graded material at bell when rate of lowering is very slow

Fig. 17—Distribution of closely graded ore and coke with charging cycle CCCCCCCC OOOOOOOO

Fig. 18—Charging cycle
CCCCOOOO

Fig. 19—Charging cycle
OOOOCCCC

Fig. 20—Charging cycle
CCOOCCOO

Fig. 21—Charging cycle
OOCCOOCC

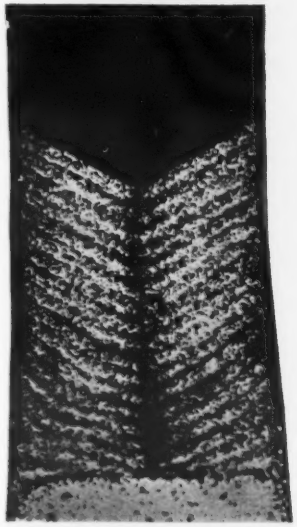


Fig. 22—Charging cycle
CCOOOOCC

Fig. 23—Charging cycle
OOCCCCOO

Fig. 24—Charging cycle
CCCCOOOO

Fig. 25—Charging cycle
OOOOCCCC

Figs. 18 to 23—Distribution of closely graded ore and coke with various charging cycles
Figs. 24 and 25—Distribution of widely graded ore and coke with CCCCOOOO and OOOOCCCC charging cycles

P11.M1

Fig. 26—Charging cycle CCCCOOOO (cf. Fig. 18)

Fig. 27—Charging cycle OOOOCCCC (cf. Fig. 19)

Fig. 28—Charging cycle CCOOCCOO (cf. Fig. 20)

Fig. 29—Charging cycle OOCCOOCC (cf. Fig. 21)

Fig. 30—Charging cycle CCOOOOCC (cf. Fig. 22)

Fig. 31—Charging cycle OOCCCCOO (cf. Fig. 23)

Fig. 32—Charging cycle CCCCOOOO (cf. Fig. 24)

Fig. 33—Charging cycle OOOOCCCC (cf. Fig. 25)

Figs. 26 to 31—Distribution of closely graded ore and coke with various charging cycles when large-bell load of eight skips is loaded into hopper and charged to main bell before dumping

Figs. 32 and 33—As above, but with widely graded materials

seen more clearly in Fig. 36, where the mean stream paths are shown plotted against the distance fallen, the inflection point changing from about 1·2 in. below the lowered bell for very rapid dumping to about 1·7 in. below the bell for the slowest dumping.

Distribution experiments were carried out with 10–20 and 40–60-mesh limestone with these three dumping rates in the manner described previously, and the results obtained are shown in Figs. 13, 14, and 15. As before, the broad outline of the distribution is the same, but with the slowest dumping the stockline can be seen to be noticeably flattened at the walls (Fig. 13), and in both this and Fig. 14 (medium dumping rate) a small increase in coarse material may be seen at the walls. The distributions of coarse material across the model in the extreme experiments, calculated from Figs. 13 and 15 by particle counts, are shown in Fig. 39, where the effect of slower dumping is plainly visible.

A further effect of slow dumping may also be noted here although it is not connected with the velocity of materials leaving the bell. If the rate of lowering is very slow and the burden has a wide grading there may be a considerable size segregation of materials at the bell owing to the fine material filtering through the slowly opening bell and being charged first, leaving the larger lumps in the hopper. Limestone of a very wide grading (6–200-mesh) with the intermediate sizes removed was used for these experiments, and the bell was lowered very slowly; Fig. 16 shows the manner in which fine material is charged first, leaving the coarse material in the hopper.

NATURE OF MATERIALS CHARGED

The physical characteristics of the materials to be charged will certainly exert an influence upon their line of fall to the stockline, the factors to be grouped together in this respect being (*a*) size, (*b*) shape, (*c*) density, and (*d*) moisture content.

Size

The influence of particle size upon the trajectory on leaving the bell was discussed in Part I,[1] when it was shown that the smaller particles fall more vertically than the larger ones. The effect of this upon the distribution of particles consequent upon an **M** stockline has been considered more fully, as it may be of critical importance.

M stocklines with identical contours may be obtained in two ways, namely, (i) by using a bell of small size relative to the size of the throat and (ii) by using a larger bell and a deflecting ring (or plates in the case of a slice model) suitably situated below it. A slice model of a furnace throat was equipped with interchangeable head-gear designed to give stocklines of identical **M** contours by each of these means. A mixture of 8–10 and 60–100-mesh limestone was charged and the stock was separated into vertical compartments and subjected to sieve analysis in the usual manner.

The characteristics of the head-gear and operation employed to achieve the **M** stockline by the two methods are (1) bell/throat ratio 0·40, bell drop $\frac{3}{8}$ in., stockline height 1 in. below closed bell, and (2) bell/throat ratio 0·70, deflecting plates 30° from vertical inserted in the path of the falling material, bell drop $\frac{3}{8}$ in., stockline height $1\frac{7}{8}$ in. below closed bell. The contours of the stocklines obtained are shown in curves *D* and *B* of Fig. 40 and the distribution of coarse and fine material is illustrated in Fig. 41 (curves *D* and *B*). It will at once be seen that the distributions are completely different. With the small bell there is a marked excess of coarse material at the walls and a deficit at the centre, whilst with a large bell and deflecting plates the distribution is reversed, the excess of coarse material being at the centre and of fine material at the walls.

These opposite distributions are due to the differences in the trajectories of the coarse and fine material in the falling stream. With a small bell the coarse material is on the outside of the falling stream and hence strikes the outer slope of the **M** and rolls to the walls, giving an excess in this region, whereas with a large bell and deflecting plates the coarse material rebounds from the plates to the inside of the falling stream, strikes the inside of the slope of the **M**, and rolls to the centre.

These two experiments were repeated using a circular model of the furnace throat with two sets of head-gear which were the circular equivalents of those used on the slice model. Equivalent quantities of the same limestone mixture were charged, and the distribution was determined by separating the burden into annular compartments in the manner described in Part II.[2] The stockline contours obtained are shown in

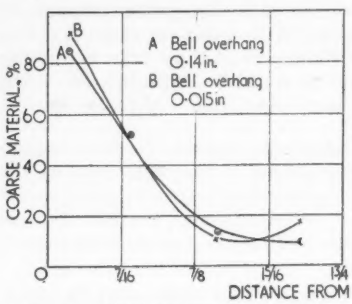


Fig. 38—Distributions of material from bells of 0·015 in. and 0·14 in. overhang, respectively (*see also* Figs. 4 and 6)

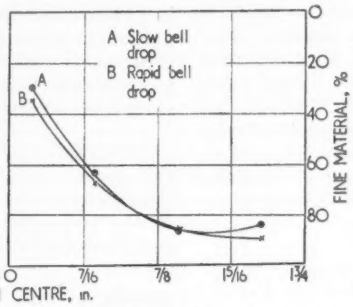


Fig. 39—Distributions of material from mixed burden charged at slow and rapid rates (*see also* Figs. 13 and 15)

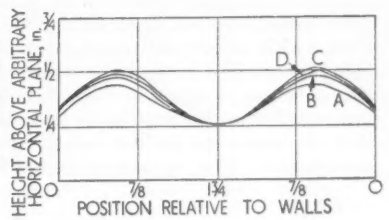


Fig. 40—Contours of M stocklines obtained with deflecting ring in circular model (curve *A*), with deflecting plates in slice model (curve *B*), with small bell in circular model (curve *C*), and with small bell in slice model (curve *D*)

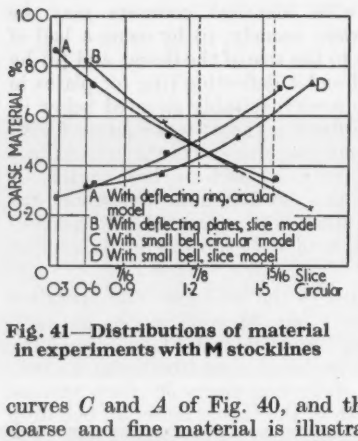

COARSE MATERIAL, %
A With deflecting ring, circular model
B With deflecting plates, slice model
C With small bell, circular model
D With small bell, slice model
Slice
Circular

Fig. 41—Distributions of material in experiments with M stocklines

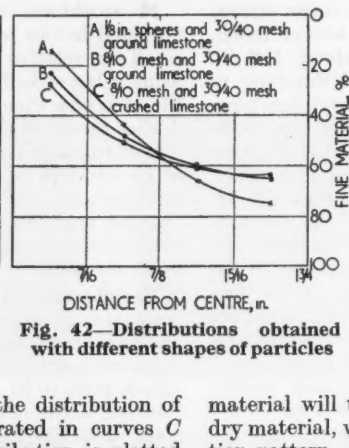

A ⅛ in. spheres and 30/40 mesh ground limestone
B 8/10 mesh and 30/40 mesh ground limestone
C 8/10 mesh and 30/40 mesh crushed limestone
FINE MATERIAL, %
DISTANCE FROM CENTRE, in.

Fig. 42—Distributions obtained with different shapes of particles

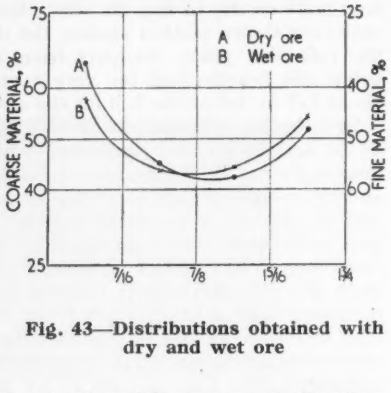


Fig. 43—Distributions obtained with dry and wet ore

curves *C* and *A* of Fig. 40, and the distribution of coarse and fine material is illustrated in curves *C* and *A* of Fig. 41, where the distribution is plotted against the square of the distance from the centre in order that direct comparison may be made with curves 1 and 2 for the slice model (*see* Part II). It can be seen that the distribution is very similar in each case to that found in the slice model.

With a **V** stockline, where all the material strikes the walls at or above the stockline, or with an inverted **V** stockline, where all the material strikes the central region, size segregation in the trajectory will have no effect, as there is in each case only one direction for segregation by rolling to take place.

Shape

The trajectories of spherical and angular particles were recorded in Part I.[1] The effect of the degree of angularity on the distribution of coarse and fine materials has also been investigated. Here the differences in distribution are not only due to the change in the trajectory of the particles but also to differences in freedom of motion at the stockline. The characteristics of the limestone particles used were (1) ⅛-in. spheres and 30–40-mesh ground particles, (2) 8–10-mesh ground lumps and 30–40-mesh ground particles, and (3) 8–10-mesh crushed lumps and 30–40-mesh crushed particles. The spheres were formed in a pill-making machine, the ground material by prolonged grinding in an edge-runner mill, and the crushed material by means of a jaw crusher; the three experiments involved thus represent a gradual transition from spherical to angular material, and were carried out in a slice model of the furnace throat fitted with a normal head-gear, the distribution being determined in the usual manner. The distribution obtained is shown in Fig. 42, from which it may be seen that as the angularity increases the segregation decreases, as keying and hanging of particles prevent the rolling of coarse material to the centre.

Density

The effect of density upon the velocity off the bell and upon segregation has been considered in Part I.[1]

Moisture Content

Wet sticky material will obviously tend to stick and hang on the bell and hence leave it at a much slower rate than dry free-flowing material. Such material will thus tend to fall more vertically than dry material, with a consequent alteration in distribution pattern. The sticky nature of the material will also lessen the movement of particles at the stockline and thus diminish segregation.

Two experiments were carried out in a slice model of the furnace throat. In each case alternate layers of 20–40-mesh coke and an intimate mixture of 10–20 and 40–60-mesh Northants ore were charged, the bell/throat ratio being 0·65 and the stockline height 1·5 in. from the closed bell; in one case the ore was dry, whilst in the other it contained 15% of water. At the end of each experiment the stock was divided into vertical compartments in the manner previously described,[2] and the ore from each compartment was separated by sieving, the moist ore being dried before separating. With dry ore the layers were of approximately even thickness and the contour of the ore layer was **V**-shaped and lipped near the wall; the crest of the lip was 0·15 in. from the wall, and the trough of the **V** was about 1 in. below this crest. When wet material was used the ore fell more vertically, the crest of the lipped **V** being about 0·25 in. from the walls, and less rolling took place, giving a deeper **V** with a trough about 1·2 in. below the crest; there was thus a greater relative quantity of ore nearer the walls than at the centre. The size distribution in the ore layers obtained in each experiment is shown in Fig. 43. It can be seen that whilst in each case this distribution is that associated with a lipped **V** stockline, the overall size segregation is greater with dry ore, this segregation being most marked at the centre. With moist ore there is not as great an excess of coarse ore at the centre but rather more at the walls, as could be expected, since the stockline contour is moving from a **V** to an **M**.

Kennedy[3] investigated certain of the factors influencing the trajectories of materials leaving the bell, using a chute representing a section of the radius of the large bell; the conclusions reached by him were essentially the same as those recorded above.

EFFECT OF VARIATION OF CHARGING CYCLE

The alteration in the charging cycle, *i.e.*, the order of loading materials on to the large bell, is known to be able to exert a marked effect on the operation of

the furnace without the reason for this being fully understood, and it was decided to see whether there was any obvious difference in the distribution consequent upon such an alteration.

A slice model with a simple head-gear consisting of a single bell (bell/throat ratio 0·72) and a skip of such a size that eight skip loads constituted one large-bell load was used for these experiments. Closely graded materials (20–40-mesh coke and ore) were employed, a dense ore (density 4·0) being used to secure the maximum density difference between it and the coke.

Charging Cycle CCCCCCCC|OOOOOOOO

In the first experiment the charging cycle was CCCCCCCC|OOOOOOOO, giving alternate layers in the model (*see* Fig. 17). The difference in the angles of repose (coke 40°, ore 36°) did not appear to produce any marked differences in layer thickness across the model, but there was a noticeable thickening of the ore layers at the walls owing to this material forcing the coke away from the walls at the point of impact. There was also a certain amount of mixing of coke and ore at the coke/ore interface where the coke was uppermost. Layer charging, with the consequent reduction of the annular segregation of coke and ore, is likely to improve furnace efficiency but at the same time and for the same reason retard the driving rate of the furnace.[5]

Charging Cycles (1) CCCCOOOO and (2) OOOOCCCC

With a charging cycle of CCCCOOOO two well-marked zones of excess coke were formed, at the walls and the centre, with zones of excess ore between them (*see* Fig. 18). When the experiment was repeated with the ore loaded on to the bell first (OOOOCCCC) the distribution of coke and ore was found to be quite different, the zone of excess coke at the centre being greatly reduced in width whilst that at the walls was replaced by a zone of excess ore. There was also less mixing of the coke and ore, the separate layers being more clearly defined across the model (*see* Fig. 19). These two experiments were repeated in a circular model with a similar head-gear, the volumes charged being adjusted to give the same layer thickness as those obtained in the slice model. The distribution of coke and ore was obtained by dividing the model into annular compartments by means of cylindrical tubes and separating the coke and ore in each annulus by flotation with bromoform. It can be seen from Fig. 44 that this distribution is essentially the same as that obtained in the slice model, *i.e.*, where coke is loaded first the excess of coke at the centre is much greater and the maximum ore is in the intermediate position, and where ore is loaded first there is a smaller excess of coke at the centre and the maximum ore is at the walls. This difference in the distribution of coke and ore, especially at the walls, may explain why in lean-ore practice it is found that the furnace works better with coke first on the bell, since in this practice an outer annulus of coke, with free burning at the walls, is known to be advantageous.[5]

With ore loaded first there is little mixing during the fall to the stockline and thus distinct layers of coke

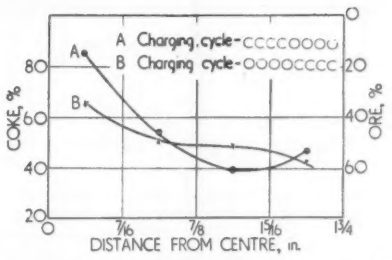


Fig. 44—Annular distribution of ore and coke with CCCCOOOO (curve *A*) and OOOOCCCC (curve *B*) charging cycles in circular model

and ore are formed, the excess of coke at the centre being produced by the preferential rolling of coke to the trough. The ore falls on to the coke layer and, as previously noted, the impact of the ore forces some of the coke away from the wall, giving an excess of ore in this position. When coke is charged first there is considerably more mixing during the fall to the stockline, but the material which first reaches it and builds it up is mainly coke. Thus the ore falls on a stockline of rolling coke and is carried with it away from the walls. The lighter coke, however, rolls further and forms the zone of excess coke at the centre.

These results are somewhat similar to those obtained by Furnas and Joseph,[4] using rather larger semi-circular models. Exactly similar results could not be expected, as these workers used relatively large coke and fine ore.

Charging Cycles (1) CCOOCCOO and (2) OOCCOOCC

The distribution of coke and ore with CCOOCCOO and OOCCOOCC charging cycles (Figs. 20 and 21) is essentially very similar to that produced when only two layers are loaded on to the bell in the corresponding order, but with greater mixing of coke and ore in both cases.

Charging Cycles (1) CCOOOOCC and (2) OOCCCCOO

With CCOOOOCC and OOCCCCOO charging cycles (Figs. 22 and 23) the distribution of coke and ore is, in general, that associated with coke loaded first and ore loaded first, respectively. As in the last pair of experiments, there is considerable mixing of layers.

Charging Cycles (1) CCCCOOOO and (2) OOOOCCCC with Widely Graded Materials

The experiments where the charging cycles were CCCCOOOO and OOOOCCCC were repeated, using materials having a wide grading (*i.e.*, equal volumes of 10–20, 20–40, 40–60, and 60–100-mesh). The segregation of coke and ore was, in general, similar to that obtained using closely graded materials, *i.e.*, coke at the walls and centre and ore intermediately in the first case, and coke at the centre and ore at the walls in the second. Superimposed on this was the normal size segregation, namely coarse material at the centre, changing to fine material at the walls (*see* Figs. 24 and 25).

CHARGING FROM NON-ROTATING DOUBLE-BELL SYSTEM

In order to ascertain whether or not any appreciable mixing of the ore and coke takes place during

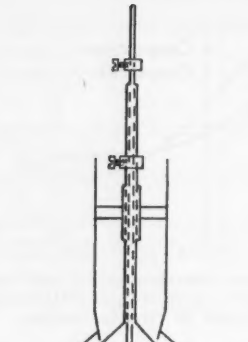


Fig. 45—Non-rotating double-bell system

the transference of the material from the small hopper to the large bell, the charging-cycle experiments with both closely graded and widely graded materials were repeated using a simple non-rotating double-bell system (Fig. 45). The whole large-bell load of eight skips was first loaded in the small hopper in the desired sequence and then charged on to the main bell and dumped. Whilst this represents a departure from normal practice it provides the maximum opportunity for mixing during the transference.

Charging Cycles (1) CCCCOOOO and (2) OOOOCCCC with Closely Graded Materials

With CCCCOOOO and OOOOCCCC charging cycles and closely graded materials (Figs. 26 and 27) the segregation is in each case very similar to that obtained with a single bell (*cf.* Figs. 18 and 19).

Charging Cycles (1) CCOOCCOO, (2) OOCCOOCC, (3) CCOOOOCC, and (4) OOCCCCOO with Closely Graded Materials

Where (1) CCOOCCOO, (2) OOCCOOCC, (3) CCOOOOCC, and (4) OOCCCCOO charging cycles were employed the same general distribution patterns (Figs. 28 to 31) were obtained as in the corresponding single-bell experiments (Figs. 20 to 23), although in both cases where ore is loaded first the excess of ore at the walls is somewhat less than in the analagous single-bell experiment.

Charging Cycles (1) CCCCOOOO and (2) OOOOCCCC with Widely Graded Materials

Using the same widely graded burden as before and charging cycles of CCCCOOOO and OOOOCCCC the distribution of ore and coke is in general similar to that found in the single-bell experiments. The excess of coke at the centre in the first case (Fig. 32) is less well marked than previously (*see* Fig. 24), whilst that in the second case (Fig. 33) is greater than in the earlier experiment (*see* Fig. 25).

EFFECT OF ROTATION OF THE SMALL BELL AND HOPPER

Several investigators have pointed out the importance of uniform distribution around the periphery of a furnace and the ill effects on blast-furnace performance of maldistribution around the stack.[6,7,8] In view of this and of the extensive use of the McKee top in blast-furnace practice it was considered desirable to carry out a general survey of the modifications in distribution introduced by the employment of such a rotating top. For this work a circular model of the furnace throat (of the form previously described in Part II) was used, together with a model of a revolving top. This head-gear (Fig. 46), which was constructed of metal with all faces turned, was a $\frac{1}{10}$th scale replica of a McKee top including chute, hopper, and two bells, with the exception that normally only one skip (*S*) was used for loading. The revolving hopper (*h*) and the small bell (*b*) were interlocked and turned, as required, by hand, the arc of rotation being shown by a pointer (*P*) travelling over a graduated circular scale (*C*), with the aid of the indicator (*I*). The material was introduced into the skip, which besides being constructed to scale was in the same position and had the same tipping angle as in practice, and then loaded into the small hopper, which was always returned to the 0° position for this operation, care being taken to keep the tipping rate the same in all experiments. The hopper was then rotated to the desired position and the material charged on to the large bell by depressing the lever A_1. When sufficient material had been charged on

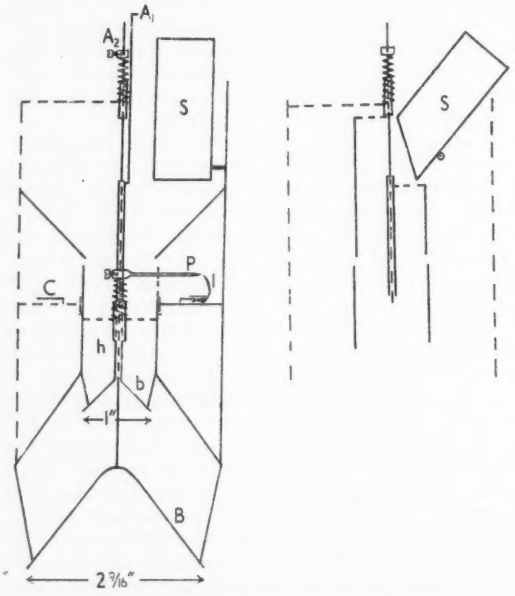


Fig. 46—Head-gear for revolving-top experiments. The revolving hopper *h* and the small bell *b* can be interlocked and turned as required. The arc of rotation is shown on a scale *C* by a pointer *P*, with the aid of an indicator *I*. The small bell is lowered by means of lever A_1 and the large bell by lever A_2

to the large bell it was dumped on to the stockline by depressing the large-bell rod A_3. When a bed of sufficient depth had been obtained the head-gear was removed and the burden separated vertically into compartments in one of two ways. In the first a set of concentric cylinders was inserted through the burden in the normal manner, dividing the material annularly and thus enabling the mean distribution from the wall to the centre to be found. This is referred to throughout as radial distribution. The second manner of sectioning was by the use of a separator constructed by soldering together radially eight strips of metal, each of width equal to the radius of the model, so as to form eight equal sectors ; the top was fitted with a wooden cover having $\frac{1}{2}$-in. holes, normally closed with corks, drilled above each sector. This separator was inserted through the burden and the contents of each sector were removed in turn by inverting the model and removing the appropriate cork. The distribution obtained by this method is referred to throughout as circular distribution. The terms loading, charging, and dumping refer throughout to the transfer of material from the skip to the small hopper, from the small hopper to the large bell, and from the large bell to the stockline, respectively. The term sequence refers to the series of operations between successive dumps of the large bell, and cycle to the series of dumpings of the large bell before returning to the initial conditions.

LOCATION OF A SINGLE SKIP LOAD OF MATERIAL

The location of a single charge of material, which formed part of a sequence, in the model was first investigated. In the first instance 20–40-mesh marble was used for the burden, the particular charge the location of which was required being coloured black. The sequence employed was as follows :

Load 2 skips ; rotate 0° : charge
Load 2 skips ; rotate 90° ; charge
Load 2 skips ; rotate 180° ; charge
Load 2 skips ; rotate 270° ; charge
Dump
Repeat sequence

The particular charge was the first in the second sequence. Two skip loads were used for a charge in this first experiment in order to increase the thickness of the layer formed by the special charge. From visual observation and measurements of the layer thickness at the periphery it appeared that the particular charge was distributed reasonably uniformly around the shaft.

In order that quantitative measurements of the distribution of a particular charge could be carried out, the main bulk of the material used was 20–40-mesh porcelain with the special charge of 20–40-mesh marble, the physical properties of these materials being sufficiently similar to ensure that they did not cause segregation. The previous experiment was repeated except that one skip load was used for each charge. At the conclusion of the experiment the burden was divided with the sector separator, the contents of each sector being removed in turn and the proportion of marble in each determined by treatment with excess acid and back titration. The

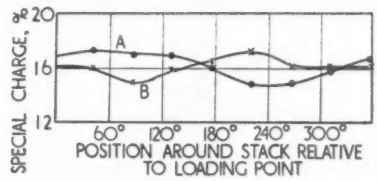


Fig. 47—Circular distribution of particular charges introduced at 0° (curve *A*) and 180° (curve *B*) in revolving-top experiments

circular distribution of the particular charge is shown in Fig. 47 (curve *A*). A repeat experiment was carried out in which the special charge was the third in the second sequence instead of the first, and the circular distribution, obtained in the same manner as before, is shown in Fig. 47 (curve *B*). It can be seen from these curves that there is an appreciable maximum in the volume of the special charge some 60° in advance of the charging position and a minimum some 180° from this position ; there is, however, very little difference between the maximum and minimum volumes of the special charge, the former being about 17% and the latter about 15%. This relative uniformity of the circular location of any given charge was confirmed by charging similar material (20–40-mesh marble) at one position only (0°). The **V**-shaped stockline produced showed no appreciable asymmetry, certainly not enough to influence the movement of large material at the stockline.

It is of interest to compare this result with certain observations of the stockline of the Consett No. 3 furnace, which is fitted with a McKee revolving top, made immediately previous to its being blown in. A single load of Sierra Leone ore, containing a high proportion of fines, was dumped on to a coke stockline to complete the filling, and examination showed that this was located almost entirely around the periphery of the **V**-shaped stockline, only a few large lumps having rolled towards the centre. The ore was fairly uniformly distributed around the walls, but with a slight excess at a point some 100° in advance of the tipping position.

SEGREGATION OF A MIXED-SIZE BURDEN

In all experiments in which a mixed-size burden was employed the skip was filled with alternate layers of 10–20 and 40–60-mesh marble, ten in all, from a small measure. This was loaded into the small hopper, charged on to the large bell, and, at the completion of a sequence, dumped into the model. When a bed of sufficient depth had been obtained the head-gear was removed and the burden analysed for circular distribution. Certain of the experiments were repeated and the radial distribution found.

VARIATION OF ANGLE OF ROTATION BETWEEN CHARGES

Loading at One Point Only, *i.e.*, 360° between Charges

Sequence
Load 1 skip ; rotate 0° ; charge ; repeat ;
4 charges in all ; dump ; repeat ;
4 dumps in all

The radial distribution with the above sequence and loading at one point only is shown in curve *A*,

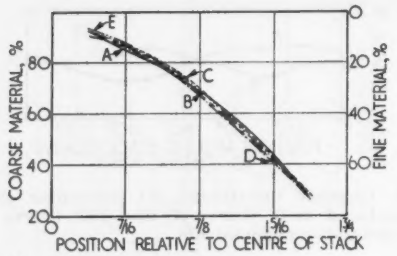

COARSE MATERIAL, %
FINE MATERIAL, %
POSITION RELATIVE TO CENTRE OF STACK
A 360° between charges
B 90° between charges
C 90° between charges ; 5 operations per sequence
D 4 charges at each 90° position
E Direct filling of small hopper

Fig. 48—Radial distributions of coarse and fine materials with revolving head-gear operated in varying ways

Fig. 48, and can be seen to be that associated with a large bell of this size (bell/throat ratio 0·72), *i.e.*, fine-mesh material in excess at the walls, changing to predominantly coarse material at the centre. The circular distribution is shown in curve *A*, Fig. 49, and shows a well-marked maximum of coarse material situated in the sector 90° in advance of the charging position. When the hopper is rotated to the 180° position for each charge this maximum is displaced by 180°, as can be seen from curve *B*, Fig. 49.

Charging at Two Positions Separated by 180°

Sequence
Load 1 skip ; rotate 0° ; charge ;
Load 1 skip ; rotate 180° ; charge ;
Load 1 skip ; rotate 0° ; charge ;
Load 1 skip ; rotate 180° ; charge ;
Dump ; repeat ;
4 dumps in all

The circular distribution, depicted in curve *C*, Fig. 49, shows an excess of coarse material at two positions, each located in the sector 90° in advance of the charging positions. This excess of coarse material is not so large as in the previous experiments where charging was carried out at one position only.

Charging at Three Positions Separated by 120°

Sequence
Load 1 skip ; rotate 0° ; charge ;
Load 1 skip ; rotate 120° ; charge ;
Load 1 skip ; rotate 240° ; charge ;
Load 1 skip ; rotate 0° ; charge ;
Load 1 skip ; rotate 120° ; charge ;
Load 1 skip ; rotate 240° ; charge ;
Dump ; repeat ;
3 dumps in all

The circular distribution (curve *D*, Fig. 49) shows that there are now three regions of maximum coarse material, each situated in approximately the same positions relative to the charging points. The degree of segregation, however, is now comparatively small.

Charging at Four Positions Separated by 90°

Sequence
Load 1 skip ; rotate 0° ; charge ;
Load 1 skip ; rotate 90° ; charge ;
Load 1 skip ; rotate 180° ; charge ;
Load 1 skip ; rotate 270° ; charge ;
Dump ; repeat ;
4 dumps in all

The radial distribution was found and curve *B*, Fig. 48, shows that it is practically identical with that obtained with no rotation of the small bell.

The circular distribution (curve *E*, Fig. 49) now shows no regions of excess coarse material which can be associated with the charging points, the distribution of coarse and fine-mesh material being practically uniform in all sectors.

To sum up the results of this series of experiments, the extent of segregation around the stack decreases as the angle between charges is reduced, until in the case where the rotation between charges is 90°, circular segregation has almost disappeared. The radial distribution remains unaffected, however, that found in the two extreme cases being substantially the same.

ALTERNATIVE METHODS OF CHARGING

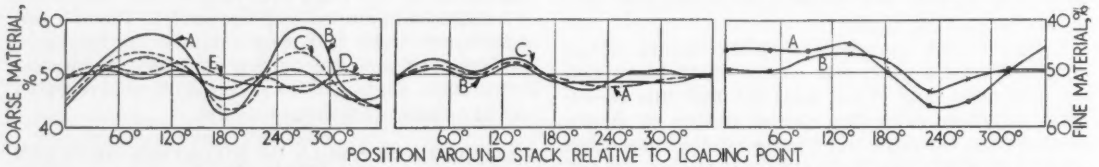
Spiral Charging

Spiral charging is often employed in practice so that any inherent segregation associated with the particular sequence used is not immediately repeated in the same vertical position. A simple example of this type of charging was investigated, in which the sequence was as follows :

Load 1 skip ; rotate 90° ; charge ;
Load 1 skip ; rotate 90° ; charge ;
Load 1 skip ; rotate 180° ; charge ;
Load 1 skip ; rotate 270° ; charge ;
Load 1 skip ; rotate 0° ; charge ;
Dump

Repeat, advancing the initial charging position by 90° in each sequence, four sequences completing the cycle

The distribution was analysed radially and circularly ; again the former showed no appreciable alteration from the standard pattern (Fig. 48, curve *C*).



A 360° between charges. Charging at 0°
B 360° between charges. Charging at 180°
C 180° between charges
D 120° between charges
E 90° between charges

Fig. 49—Circular distributions of coarse and fine materials with varying angles of rotation between charges

A 90° between charges
B 90° between charges; 5 operations per sequence
C 4 charges at each 90° position

Fig. 50—Circular distributions of coarse and fine materials with alternative methods of charging

Fig. 51—Circular distributions of coarse and fine materials in control experiments. Curve *A*, typical individual experiment; curve *B*, mean of several experiments

The circular distribution (Fig. 50, curve *B*) is substantially uniform, showing a slight improvement over that obtained with a simple cycle with 90° rotation between charging points (Fig. 50, curve *A*).

Rotation between Successive Dumpings Only

Sequence
Load 1 skip ; rotate 0° ; charge ;
Load 1 skip ; rotate 0° ; charge ;
Load 1 skip ; rotate 0° ; charge ;
Load 1 skip ; rotate 0° ; charge ;
Dump

Repeat, advancing the rotation by 90° in each sequence, four sequences completing the cycle.

The distribution was analysed both radially and circularly ; the radial distribution (curve *D*, Fig. 48) remains unaltered, whilst the circular distribution (curve *C*, Fig. 50), although still reasonably uniform, is not so good as that obtained with the other cycles employing charging at four points separated by 90° (*cf.* curves *A* and *B*, Fig. 50).

It is interesting to compare results obtained in control experiments where the material was loaded directly into the small hopper. Alternate layers of 10–20 and 40–60-mesh material were loaded as uniformly as possible from a small measure, ten such layers constituting a charge. There were four such charges to a dump and four dumps were made in all without any revolution of the small hopper. The radial distribution (Fig. 48, curve *E*) was virtually identical to those obtained previously. The circular distribution varied somewhat in individual experiments. Figure 51, curve *A*, shows the extent of segregation in one typical experiment, whilst curve *B* shows the distribution for a mean of several experiments. The degree of segregation obtained under these conditions—which correspond to good hand charging in practice—can be seen to be intermediate between that obtained with adequate rotation and without rotation of the small bell (Fig. 49).

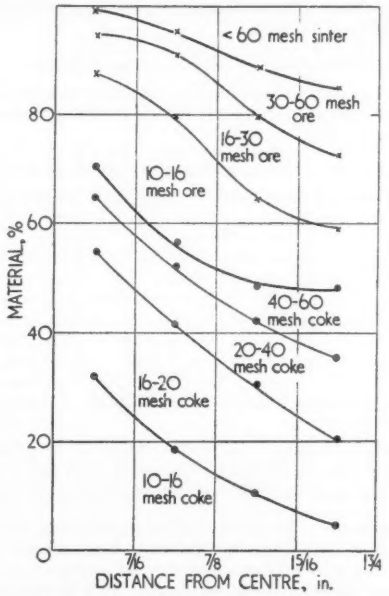


Fig. 52—Radial distributions of materials in experiment based on works practice

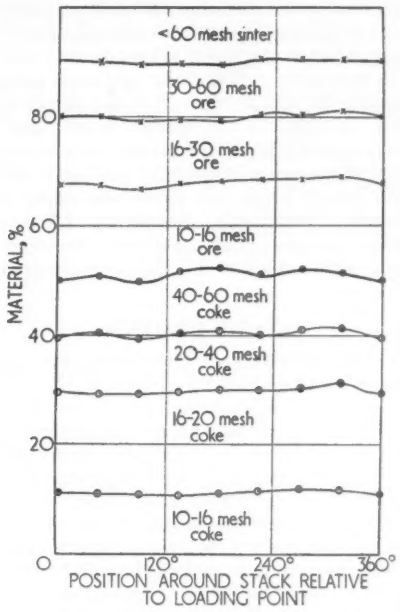


Fig. 53—Circular distributions of materials in experiment based on works practice

CYCLE BASED ON WORKS PRACTICE

A final experiment was carried out in which the burden and charging cycle are based on that employed in works practice. For this experiment a second skip was employed, located 180° from the first and tipping from the same side. The burden employed was as follows :

Ore (a home ore, density 2·4), 1–6 in., predominant size 3–6 in. Represented by a mixture of 2 parts 10–16, 1 part 16–30, and 1 part 30–60-mesh.

Coke 1–6 in., predominant size 3–4 in. Represented by a mixture of 1 part 10–16, 2 parts 16–20, 1 part 20–40, and 1 part 40–60-mesh.

Sinter 1 in. to fines. Represented by < 60-mesh.

Charging was carried out as follows :

Sequence	Left-Hand Skip	Right-Hand Skip	Charged from Small Bell at
1	10 c.c. ore	10 c.c. ore	0°
			0°
	10 c.c. coke	10 c.c. coke	0°
			0°
2	As (1)		45°
3	10 c.c. sinter	10 c.c. sinter	90°
			90°
	10 c.c. coke	10 c.c. coke	90°
			90°
4	As (1)		135°
5	As (1)		180°
6	As (3)		225°
7	As (1)		270°
8	Repeat of (1)		315°

This series of operations should then be repeated, moving back by 45° until the spiral is complete. This, however, was not practical owing to the limitations

of the model, so the distribution analysis covers only the $\frac{1}{8}$th cycle detailed above. Both radial and circular distributions were obtained (Figs. 52 and 53). The radial distribution follows the pattern association with large bells of this size (bell/throat ratio 0·72), *i.e.*, large material to the centre, small material to the walls, excess coke at the centre, excess ore at the walls (note that ore was charged first on to the large bell), the sinter, which was dense and small, mainly at the walls. The circular distribution of material is reasonably uniform, the maximum variation from uniformity, from 15·7 to 17·8%, occurring with the large ore.

CONCLUSIONS

From the experiments described the following conclusions can be drawn :

(1) Increased bell overhang and increased extent and rate of bell opening all give increased throw of materials to the walls, with consequent alteration in segregation, especially with high stocklines.

(2) Since fine material has a more vertical line of fall from the bell, large lumps will always be on the outside of the falling stream, thus an **M**-shaped contour derived from a bell of small bell/throat ratio will have the coarse material mainly at the walls whilst a similar contour derived by rebound of material from a deflecting ring will have the coarse material mainly at the centre.

(3) The more angular the lumps the less will be the segregation at the stockline. A similar diminution of segregation will be brought about by a moist burden.

(4) The ore/coke cycle, *i.e.*, the order of charging ore and coke on to the bell, has a considerable effect on the segregation. With coke first on the bell there is a well-marked excess of coke at the walls and the centre. With ore first on the bell there is a more marked layer formation in the stack, with an excess of ore at the walls and a narrow zone of excess coke at the centre.

(5) The effects noted under (4) are well marked over a range of different cycles, the order of charging ore and coke on to the bell being the important criterion. The use of a widely graded burden does not alter the segregation of ore and coke but imposes the normal size segregation upon it. The use of a double-bell system instead of a single bell does not appreciably alter the segregation of coke and ore.

(6) By the use of a McKee top, uniform circular distribution of materials around the stack may be obtained, *i.e.*, the proportion of coarse and fine materials in any segment of the cross-section will be similar.

(7) The use of a McKee top has no effect upon the radial distribution of materials in the stack, the distribution of coarse and fine materials across a diameter of the furnace being the same whether or not such a top is used.

Acknowledgment

The author wishes to thank Dr. H. L. Saunders for his continued interest in this work and for his many helpful suggestions.

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Standardization of Tube Sizes

The Sintered Oxides Sub-Committee of the Inter-Service Metallurgical Research Council (Ministry of Supply and Admiralty) has held discussions with manufacturers with the aim of improving the supply of tubes of special refractory.

It has now been agreed to concentrate on production of a range of sizes which are to be regarded as standard henceforward. The manufacturers have undertaken to maintain stocks of the standard sizes, so that orders may be met from articles in stock.

Those employing large numbers of tubes are asked to standardize their sizes at the earliest possible moment and those designing new apparatus are asked to use standard sizes wherever possible. Production of the standard items will commence immediately. Non-standard tubes will be obtainable, but their delivery may still be subject to delay.

Tube standardization details are as follows :

1. The materials involved are (*a*) Impervious alumina, and (*b*) Impervious mullite for use at temperature up to 1700° C.

2. The cross-sections of the standard sizes are :

Internal dia., mm.	Wall thickness, mm.
5	1·5
10	2·0
15	2·5
25	3·0
40	4·0
50	4·5
65	5·0
75	5·5

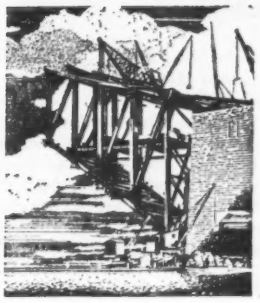
All tolerances will be as stated by the individual manufacturers.

3. Standard tubes will be available in lengths up to 900 mm. with both ends open, and also with one end open and the other hemispherically closed.

Thermocouple insulator.—Whilst dealing with tube standardization, the opportunity has been taken to introduce a standard cross-section of impervious alumina twin-bore thermocouple insulator. It will have an oval section, with 3·5 mm. major, and 2·0 mm. minor axes with 1 mm. bores, and 1·5 mm. between centres.

IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE TWELFTH MEETING

THE TWELFTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at 4 Grosvenor Gardens, London, S.W.1, on Thursday, 23rd March, 1950. Mr. W. F. CARTWRIGHT (Steel Company of Wales, Ltd.), Chairman of the Group, was in the Chair, except for a short period at the end of the Afternoon Session, when his place was taken by Mr. W. J. POOL.

The MORNING SESSION was devoted to the presentation and discussion of two papers entitled "Traffic of Iron and Steel Works—A Method of Traffic Analysis," by H. H. MARDON and M. D. BRISBY (B.I.S.R.A.), and "Traffic of Iron and Steel Works—The Application of Very High-Frequency Radio Communication," by H. H. MARDON, H. A. CHAPMAN, and M. D. BRISBY (B.I.S.R.A.).

PROCEEDINGS OF THE MORNING SESSION: 10.30 A.M. to 1 P.M.

Joint Discussion on the Papers—
TRAFFIC OF IRON AND STEEL WORKS—A METHOD OF TRAFFIC ANALYSIS* and TRAFFIC OF IRON AND STEEL WORKS—THE APPLICATION OF VERY HIGH-FREQUENCY RADIO COMMUNICATION†

The authors briefly introduced their papers.

Mr. **C. H. T. Williams** (Park Gate Iron and Steel Co., Ltd.): In the iron and steel industry there is a greater consciousness of the major production processes and their equipment than of the services which make this production possible. Of these services the traffic system is one of the most important and merits considerable attention. There may be a traffic department which is so well provided that it can meet all demands without undue strain, but I believe this to be the exception, and even then the service may be given at a cost which could be improved. The saving of one locomotive from full-time service on a 7-day week and for, say, a 50-week year (that is the system today in most works) represents about £10,000.

In many works the position is somewhat different; the not-so-distant war years have left their mark on the condition of locomotives and track, and even on operating procedure. Post-war improvements in production have increased the traffic demands, and these have been met often in circumstances of some difficulty. When new works are planned, the railroad systems and the traffic equipment can be given consideration, but in existing works it is usually difficult, if not impossible, to rearrange routes and to revise tracks to any great extent. In these cases, improved operating procedure has to meet most of the changing requirements.

The traffic of iron and steel works is unlike that of a main-line railway, and also varies considerably according to layouts and the nature of the particular processes, so that it is necessary to find a measure which could be readily applied to compare the operating results of a works traffic department. This was the authors' first action in what is really a series of investigations.

The records of wagon utilization are available in all works but are not necessarily presented in similar form to that in Fig. 1, which is a useful picture and can be readily understood. At Park Gate this chart, which can be regarded as part of the weekly records of the department, is not only used by the management but, at the request of the men's committee, is also posted in the traffic centre for the men's information. Figures 2 and 3 in the paper need be prepared only when periodic investigations are being made.

Information on locomotive utilization is not so readily available, and I agree that this can best be secured by an investigation made by a person riding on the footplate.

* *Journal of The Iron and Steel Institute*, 1949, vol. 163, Dec., pp. 433–448.

† *Ibid.*, 1950, vol. 164, Apr., pp. 425–438.

Mechanical means are used to record the movement of a locomotive, but these fail to note the reasons for the movement.

Several investigations have been conducted, over a period of years, with the collaboration of the foremen, locomotive drivers, and shunters, and the findings have been discussed with their representatives. During the last year the method presented in this paper was tried, and proved so successful that it will be used on future occasions.

It is often the practice to use old wagons not fit for main-line working to cut down internal user charges, but I suggest that, wherever possible, wagons of special and more robust construction should be used for the internal services of heavy steelworks. It is also worth while to give similar consideration to the movement of companies' own internal user wagons as to that for main-line wagons.

The planning of the departmental processes should not, of course, be subject to the traffic service, except where they can be amended to aid the two and ultimately get better results ; but the traffic should be the servant of the production process.

The studies were conducted on steam locomotives only. I would like to know the authors' views on the use of diesel locomotives on services similar to that investigated. Would there be increased availability of the locomotives ? The service time alone averages, at best, about 12% of a shift, and rises to 19% in one of the charts. From long experience of narrow gauge railway work I can say that there is a considerable gain in using the diesel locomotives, as compared with steam locomotives.

Using this method of traffic analysis, items which do not measure up to requirements can be given attention. Among these there will probably be the need for improved communications between the traffic centre and the locomotives and their teams. In our small integrated steelworks, producing between 6500 and 7000 tons of ingots a week, it has been possible to provide a central control and service station. The works is divided into three main areas, each served by its locomotive teams under the general direction of a foreman. The control from the traffic centre is operated by a senior foreman, on each shift, who is responsible for all internal rail and road transport. He is equipped with a Post Office telephone, on which he deals with all works communications and makes contact with the railway companies and the suppliers of materials. He also has an internal works system on the *Loudaphone* principle. This is connected to ten strategic points and is especially for the use of the traffic department ; it may only be used by anyone else in an emergency. It provides two-way speaking at each point, without the use of the hand microphone, which would be objectionable in wet weather for shunters and other people. The points, of which the most distant is 1350 yards from the centre, are used by the foreman and the shunters for information and instruction. Recently, an average number of calls on the system, per 8-hour shift, was 30 outward and 15 inward calls, and on the Post Office phone was 40 calls. Control by this means is flexible, and the foremen and their teams in each area retain a measure of identity of their own within the system.

For a works of this size, we feel that this provision is adequate. On the other hand, in larger works where there may be distant departments and sidings, some other system of communication would perhaps be an advantage. Other systems have, of course, been studied by the authors and many others within and without our industry, and they have recommended the use of VHF radio communication.

One other important factor needed to make these recommendations a success is the full collaboration of all the people within the traffic department. When we are considering new equipment of this type, or for that matter any equipment for a traffic department, we must endeavour to provide means that are satisfactory to the operators and to the foremen, so that we shall get efficient operation from them. It is my opinion that there are few departments in an integrated iron and steel works where enthusiasm and intelligent interest are of more account.

Mr. **W. M. Larke** (Stewarts and Lloyds, Ltd., Bilston) : Although some locomotives are working only 50% of the time, there are times when they are working to 150% of their capacity—perhaps not very often, but in emergencies. I think it is thoroughly dangerous to try to over-organize, *i.e.*, to try to reduce the number of locomotives to such a limit that one cannot cope with extraordinary conditions which may arise.

We also have found that the method of analysis is excellent. Everybody takes a considerable interest in the week-to-week and the day-to-day working, and the men take pride in reducing their turn-round figures. During the last six months our terminal user time has been reduced from just over 3 to about 1¾ days. But accidents can happen—for example, bunching—and I fully agree with the authors that these are usually caused by mishaps on the plant. So I suggest that, having obtained the analysis, one should also look to the broader field and make a good friend of the district goods manager and his staff, because they can help considerably. We have done this, and the co-operation between us nowadays is very good ; it helps to keep down the very considerable costs that a works is bound to meet.

Our works has not quite the output of Mr. Williams' works, and it covers, I should think, approximately the same area of about 200 acres, but the traffic operations are largely confined to an area of half this size. We have experimented in a small way with radio communication, without any technical difficulty. No matter where we took the radio equipment (and we took it into some very bad places, including underneath an open-hearth furnace in the slag hole) we obtained perfectly sound communication both ways. There was a certain amount of fading, but it was not serious.

On the question of robustness, I am convinced that there is still a good deal more to be done. In the tests which we carried out, the equipment was fitted to a locomotive that was idle, and it was not subjected to the shocks of normal use.

With regard to traffic flow, I believe that in the older works, where formerly planning was probably not the strong point, a great deal must often be decided by a man who can actually see what is happening. Therefore, whilst I am very much in favour of a central control, I feel that we must not altogether remove the control from the foreman, or whoever may be actually on the site, because he can see very much better the actual situation at any moment than can a man sitting in a central control office.

As to the method of communication, we are of the opinion that the over-to-you technique is distracting and that, if the communication is to be put in the hands of the driver rather than the shunter, the driver must have something that he can deal with in the course of his ordinary duties without relaxing attention. I feel that a duplex system is therefore essential.

In regard to secrecy, *i.e.*, selective calling, I cannot, in our own case, see any point in it, and think it is an unnecessary complication. There is, of course, an enormous advantage in having this control for emer-

gencies. There may be a little difficulty in the early stages in getting co-operation between the drivers, shunters, and foremen, but I believe that, with a little patience, they would wonder in four or five weeks' time how they had managed to do the job without it before.

In the handling of the equipment, training of any personnel is rightly taking a much larger share of the industry's attention than perhaps it has done in the past. In many directions there are likely to be new types of equipment used in the steelworks which we have not had before. But when electricity was first applied to steelworks, the same problem had to be faced, and it was a very much bigger problem then, in the sense that everybody was starting from scratch. I think we should certainly accept the manufacturer's offer to train our own suitable personnel, because by this means we shall find out much more quickly how the equipment behaves and the extent of maintenance required.

Mr. **M. G. Bennett** (General Research Department, British Railways): Planning is very desirable in traffic operation, but, as Mr. Larke and others have pointed out, emergencies do arise, and therefore the system of traffic control on British Railways has always been based on planning movements as far as possible, and also on providing a control system to take care of emergencies.

Obviously it would help, as Mr. Brisby said, if the arrivals of trains could be more planned. This is a matter of co-operation between three different bodies—the consignor, the railways, and the consignee. If the commodities are put on the rail in a bunched or un-co-ordinated manner, then they must be taken through or congestion will result.

We have devoted much study to the question of wagon turn-round, because at certain times of the year it is one of our main difficulties. I strongly support the view expressed by Mr. Brisby and others that, in addition to carrying out these broad surveys by statistical methods—which show only where the hold-ups are occurring—it is necessary to investigate periodically, as we have done in our marshalling yards, goods sheds, and elsewhere, to find exactly where the hold-ups are occurring and why certain wagons are standing longer than others.

Another important point is to determine whether cutting down the standing will affect the process that the wagon is serving. It must not be forgotten that transport is purely an ancillary undertaking; its purpose is to feed the user of the materials. The real problem is to find the right compromise between wagon standage and continuous supply of commodities to the user, and this can be found only by detailed surveys in each particular case.

Can the authors say whether the increasing capacity of wagons is going to affect this problem? Our standard wagons are now of 16-ton capacity, although many are less than this at the moment. The ability of collieries, steelworks, and other people, to deal with larger-capacity wagons is one of the factors limiting the rate at which wagon capacities can be increased.

Would a greater use of capstans and turntables, traversers, etc., decrease the demand for locomotive power? Where occasional wagons have to be pulled out and re-positioned alongside a job, these implements can be very useful. If the wagon can be pulled out with a capstan, instead of calling up an engine from a long distance away, a considerable amount of engine power can be saved.

I do not believe that radio is too complex for adoption in steelworks. I know this cry is always raised when any new apparatus is introduced, but the men eventually do welcome these technical improvements. There is one advantage of the authors' signalling system over ours: A railway signalling system must always fail, if it does fail, on the side of safety, and this imposes limitations from which they are possibly more free; they can more easily revert to the old system if the radio does not work.

I regard utilization of mechanical equipment as a part of the larger and more fundamental problem of the utilization of manpower. It would be interesting to know whether, in due course, this research will be elaborated into a survey of all manpower employed in traffic in steelworks.

Finally, I should like to congratulate the authors on this work and to say, on behalf of British Railways, how very pleased we are that it is being undertaken.

Mr. **H. H. Mardon**: There is little doubt that with diesel traction, locomotive availability would increase; however, to offset the extra cost of a diesel locomotive, availability would have to increase very considerably.

We have considered the use of capstans, turntables, and traversers. Capstans are being used successfully in some works to shunt coal wagons on to tipplers. Where wagons are to be brought from an adjoining siding to a fixed point such as a tippler or crushing plant, there appears to be considerable scope for capstans. Turntables and traversers are, I think, less useful in iron and steel works, because the number of wagons involved is usually large, and because the manipulation of these mechanisms necessarily involves intercepting the flow of wagons.

The problem of wagon capacity is under consideration, and although, generally speaking, larger wagons might relieve congestion, it is very doubtful whether the quality of the track and the radii of the curves in many works could handle high-capacity wagons. Moreover, tipplers are frequently used for the discharge of coal and ore, and larger wagons might render much of the existing equipment useless.

The question of the manpower employed in the traffic departments in iron and steel works is one which my colleagues and I hope to look into shortly.

Mr. **E. R. S. Watkin** (Appleby-Frodingham Steel Co.): The authors' emphasis on the connection between traffic efficiency and low standage or internal user charges is beyond question if it means that haulage cannot be reliable or cheap in a works full of excess wagons. The repeated suggestion that wagon charges can be reduced by quicker movement is doubtful, however, as early movement of some wagons out of a given total will merely cause others to remain longer in the queue. The only solution is to reduce the total wagons standing, either by the control of supplies or by the unloading of excess material into storage. General storage is of fundamental importance, often undertaken by traffic departments but distinct from their haulage performance.

Terminal user time has two defects as a general measure of progress. Firstly, it takes account of inward traffic only, although outward standage for cargoes or inspection can be the greater problem. Secondly, it is an omnibus total requiring supplementary analysis and sample tests to distinguish areas or materials with high standage. More directly, attention should be paid to the number of wagons of each material or product standing each morning, in relation to the number handled daily. A single standage form with sectional copies can, in fact, serve for daily traffic and stockground control; for daily circulation of standage position to all departments, with their cost credits or debits on each material and product; and for addition of the works daily charge for weekly balance. Bunching before arrival is an important cause

of excess standage, particularly for materials or grades of fuel in moderate use. On this point there is a difference of opinion between the consumers requiring loads in regular daily numbers, and the railways, whose operational researches favour occasional through trains.

The need for sufficient internal wagons has been emphasized already, but unfortunately in terms of withdrawn main-line types. It should be recognized that steelworks service, with frequent loading of heavy rough material, requires all-steel wagons with strength above main-line standard. For their proper inward and outward uses, the newer and larger main-line wagons have assisted works traffic operation. The short 27-ton tippler ore wagon and 1380 cu. ft. 20-ton coke hopper have load/tare and load/length ratios which could be little improved by enlargement and bogie construction.

I think the authors are pessimistic about locomotive utilization, and I consider that it should be possible to average at least 5 hours per shift for running time, including weighing and the tilting of ladles or moving-down of wagons during unloading. Shift changing, mealtimes, fetching stores, oiling, coaling, watering, firecleaning, and smokebox emptying require about 2 hours altogether; the remaining hour is adequate for all delays, obstructions, or possible waiting for loads and instructions. All locomotives should be in the charge of traffic department foremen; continuous job control, in co-operation with the departments served, requires one foreman to three locomotives in a reasonable walking area. These locomotives should have customary duties, which their crews can foresee and be expected to complete, without being rigidly allocated or debarred from other work. Most duties should have minimum locomotive power for normal conditions, whilst a small proportion should have a margin of power, under the best supervision, for assisting wherever required.

The time for servicing steam locomotives is substantial, but the capital cost of diesel alternatives is very high. Research is desirable into means of extending the time between lubrication, and possibly into mechanical coaling.

Radio control can add little to good personal supervision, which should provide new instructions before previous work is completed and should examine the working area for potential delays ahead of the locomotives themselves. As a substitute, radio might fail to report matters which a foreman should seek and find. Communication with drivers is a defect, as shunters with closer knowledge of train contents and track surroundings should give the final instructions, mainly by signs from positions away from the footplate. I suggest that the main sphere for radio control is in layouts, not very common in iron and steel works, where operation is too thinly dispersed for personal supervision.

Mr. **M. D. Brisby**: Terminal user time cannot, of course, tell the whole story of traffic congestion; its limitations are well understood. Nevertheless it affords a simple check on the speed of wagon discharge, and since, in some works with restricted railway layouts, slow wagon turn-round is synonymous with traffic congestion, terminal user time can, in fact, be used as a measure of efficiency. We have found that there is generally less trouble with outgoing than with incoming traffic; the chief reason is that it is in the common interest to dispatch finished products as quickly as possible.

The question of stock is one of the greatest importance, and work is in progress on this subject. Somewhere there is an economic balance between standage charges and the cost of unloading and re-loading materials to and from stock.

I agree with Mr. Watkin on the need for specially constructed internal user wagons, and have often commented on the remarkable internal user fleet at his works. The reference to the purchase of old British Railway wagons was made to put forward an immediate solution at low cost.

Our figures for locomotive availability are based on numerous time studies carried out over periods of several weeks, and I do not think them pessimistic.

Finally, it is not our intention to control traffic by radio, but simply to provide the works traffic organizations with an efficient system of communications.

Mr. **R. B. Hounsfield** (University College, London): We have been told already of the importance of collaboration among works staff, and we have been warned of the dangers of over-organization. Yet radio control is a veiled form of central control which can be efficient only if all the foremen, shunters, and drivers keep reporting back so that headquarters are kept fully aware of what is happening. If headquarters are to be able to issue correct instructions, they need to be kept constantly advised of the position of every engine and even every group of wagons. Otherwise, I fear that radio control in practice might not be as efficient as is hoped.

If, on the other hand, radio is to be a 'means of intercommunication,' will the amount of information which might be bandied about be more than any one human being can absorb? If this is to be avoided, it is important that the extent to which radio is used must be very strictly limited by the works management. And further, even if there is to be no central control as such, the improved communication with the centre may gradually lead to greater reliance on the centre and less on local initiative. Would this be good or bad?

Mr. **H. A. Chapman**: I would first say that VHF radio is very flexible and, technically, equipment can be arranged to give any degree of control of works traffic, varying from rigid control by the fixed or headquarters station to straightforward exchange of information when all stations have equal status. Future systems in the iron and steel industry will probably vary in the degree of control exercised, depending on how they wish to run their traffic.

I would point out, however, that in works where some form of central control is being operated today, reporting back is obviously a necessity, and by using radio this will be facilitated and the efficiency of the system will be greatly increased.

On the other hand, using radio solely as a means of exchanging information (in our view the better arrangement) will lead to teamwork between drivers, which must surely lessen their dependence on the central control and allow more local initiative.

Mr. **E. Pittwood** (John Lysaght's Scunthorpe Works, Ltd.): Traffic analysis is not a new system that is just coming out, but a system which is working, and in my opinion it should be extended and used in every steelworks.

It is suggested, in some of the figures given in the charts, that a line usage that is not 100% does not necessarily represent full efficiency. We are shown, for example, one line where there are only two trips in the shift, and we are shown how it could easily be used to a far greater extent. But if those few trips are taking the whole of the available traffic, then that line is doing its job.

There has been a good deal of reference to time lost in locomotives standing. I, too, am inclined to comment on the figure of less than 50% of user locomotive. Mr.

Watkin demonstrated that, even on the graphs shown, the locomotives are doing more than 50% of work through the shift. Is time standing necessarily a delay ? I do not think it is always. Surely a locomotive that is standing close by waiting for a ladle that is nearly finished loading, or waiting for some ingots that are nearly ready for an urgent wagon, is really doing efficient service and providing just that service which the plant must have if it is to work efficiently.

There has been reference to the shunting out of the worst wagons. I have always been interested in the question of standage, and know something of its real value to the steel trade. To shunt out the odd wagons that are delayed—the older wagons—would not give the advantage that the authors suggest in their illustration, when they talk of saving about £185 per week. In such a case there must have been considerable credit to be gained in another direction. How can £185 be saved per week, unless the standage debit is at £185 or more ? I cannot believe that many steelworks have a regular weekly standage charge of £185. One must take into account the debit figure, and the final debit figure for the week is generally a good deal less.

With regard to communications, having communication direct with the drivers may confuse things very seriously in a busy yard. Surely what the central control needs to do is to keep in very close contact with the foreman, assistant foreman, or departmental foreman, rather than with the actual driver. The shunter, in most works, controls the actual movement of the locomotive very much more than does the driver. I should favour the system to which Mr. Williams referred, on the lines of the *Loudaphone* system, in operation at strategic points where the foreman or the shunter could quickly get into touch with his headquarters ; there the person in control could quickly keep the locomotive moving along the lines, to give the greatest benefit.

I endorse the remarks about keeping in friendly contact with the railway management so as to deal with the question of bulk deliveries, bunching, and the avoidance of congestion.

Mr. **M. D. Brisby** : Mr. Pittwood mentioned the chart showing the single-line working. The purpose of this chart was really to show how, in single-line working, congestion may be caused more by the shunting that takes place at both ends of the line, than by actual track possession. Obviously, if a locomotive is on a single line another cannot be sent along that line. It is surprising, nevertheless, how often locomotives do find themselves face to face on the same track ! The chart in question shows the importance of regulating the shunting at the terminal ends, and is not meant to prove the incapacity of working more than two locomotives on that line.

I agree with Mr. Pittwood that standing time is very often not delay, and in the example he gave—waiting for a ladle to fill—this would not have been regarded as delay. It is only when an engine is standing because of obstruction or breakdown that we should have entered the time as delay.

With regard to shunting out the worst wagons, I thoroughly endorse the advantages of the standage scheme which deals with average wagons, and I think we have made this point clear in the report. However, we have shown that economy can be effected by keeping a check on wagons which have stood for some time in the works. Answering Mr. Pittwood's question : the debit for the week examined was, in fact, considerably more than £185. The statistical study was included as an actual example to prove that it is not sufficient to deal with average wagons, and that if no effort is made to follow up stragglers unnecessary demurrage charges may be incurred.

Mr. **H. H. Mardon** : In this discussion, much stress has been laid on the question of control of locomotive working by the use of VHF radio, and this has rightly met with adverse criticism. I should again like to emphasize that we are not advocating traffic control, but traffic communication. I endorse Mr. Pittwood's comments, and believe it would be most unwise to remove the responsibility from the driver and shunter. Far from introducing a rigid system of control, radio would give a flexible organization in which driver, shunter, foreman, and traffic manager could keep in touch with each other.

I fully appreciate Mr. Williams' case for the *Loudaphone* system, but I, too, think this has limitations in a large works, and moreover it cannot be operated from the locomotive cab.

Our Director, Sir Charles Goodeve, was in the United States recently, and saw radio in use in iron and steel works locomotives. He was particularly impressed with the progressive and co-operative spirit shown by management and workers in making a success of radio in the works traffic organization.

Since the preparation of this paper, it may be of interest to know that the Royal Dutch Steelworks have installed radio. They are trying it out on six locomotives, and are very favourably impressed. The points they stress are the facility of work at night and in fog, and the rapidity of communication. They certainly are not prepared, nor are the people in the United States, to go back to the old methods of working, and they maintain that radio has paid for itself in the past six months.

Mr. **J. R. Brinkley** (Pye Radio, Ltd.) : Some of the slides that have been shown were of an installation which my Company made, at March, for British Railways. This installation has been working for fifteen months. The men like it because it is an efficient tool and because it increases safety in fog and at night. It is often felt that the men will object to radio because it means discipline where there was none before. In fact, it always gives an enormous 'lift' to the morale of the working crews, who feel they have a weapon that they did not have before.

I would say that maintenance is of vital importance. The authors suggest that it might be possible to send apparatus back to the factory for repair. We would hesitate to recommend that. Maintenance should be carried out, if not by the steel company, by the manufacturer or by an agent of the manufacturer not further away than about 20 miles from the works. In addition, it is very important that the sets should be readily interchangeable and that a spare set be held.

If we were doing the March installation again we would employ the more specialized type of set designed for locomotives, and the new and higher frequency of about 185 Mc./sec. We would definitely not recommend powers in excess of 5 W., because considerable economies in consumption and size can be effected by restricting the power to this level, which is adequate for the range involved.

Selective calling gives only a very limited degree of secrecy ; there is nothing to stop other people from picking up broadcasts and intercepting them. It is not, strictly speaking, a secret system ; it is a method of calling individual locomotives, and I thoroughly agree with those who have said that it is unnecessarily complicated and would scarcely justify its keep.

One speaker said that he did not think locomotive drivers could master the simplex procedure. I hesitate to endorse that opinion. The simplex 'press-to-talk' procedure has been adopted as standard on all police cars and on taxis where very fast operation is required. It was used by fighter pilots during the war, when split-second co-ordination was required, and I feel there is a great deal to be said for it.

The last and most important point is probably central control. It is possible to control from other points in addition to the central point. In the police schemes it is common practice to have extension telephone control lines to other headquarters—for instance, to the fire service headquarters. The operational control remains at the central point, but there is an additional switch or a row of switches which enables the central control to extend the actual speaking control of the system to further points. It is quite possible, in certain yards, to extend lines to the places from which the foremen are operating, and for the control to switch on, at request, to these foremen so that they can talk direct to their locomotives. ' This has actually been effected at March.

I feel that too much has been made of the operational difficulties. Many of the arguments that have been raised were the same as those which were raised some years ago, in connection with police working. When the police introduced radio, it was argued that it was an attempt to do away with the man on the beat, and many people opposed it on that account; but every chief constable will admit now that that is not the true function of radio. The man on the beat is still essential, whether he is a policeman or a shunter. Radio is a tool to supplement general overall efficiency, and it is only a question of using it intelligently to obtain increased efficiency.

Mr. **S. B. Lovegrove** (British Railways, Eastern Region): We find the radio at March most useful, particularly in foggy conditions when the hand signalling system is practically out of use. In the past we had to resort to systems of hooters and whistles, but this method was not too reliable, because when two pilots are at the end of the reception route it is necessary for someone to run to one driver and tell him that it is his turn to observe the hooter signals. Now, when there are foggy conditions, we can talk to the drivers and tell them what is expected of them and when to start pushing.

Under the G.P.O. licence conditions we may be called upon to cease radio communications in a national emergency. From my own viewpoint, this is a major disadvantage, but this view is not endorsed by British Railways, because we have not yet had to apply it. This means that we have to keep another loudspeaker system going and to supplement it by telephones. It is a disadvantage that we might be asked to forgo the system of radio telephones and go back to an old system, at a time when we would be expected to put forth our utmost efforts.

The question of there being one or more control points is rather controversial. In the paper, mention is made of one or more control points as the basis of the mobile system. On the railways it is most essential, for safety, that there should be only one person giving instructions. We instruct the drivers, but the foremen and the shunters are also aware of what is happening. We are controlling only the up side at Whitemoor at present. In a large steelworks, where there might be conflicting movements, there would be scope for a supplementary telephone system or a loudspeaker system, such as Tannoy, which would advise foremen and people at intermediate points of what is happening.

I anticipate that the application of radio in steelworks would result in greater efficiency, better use of the locomotives, and a quicker response to orders; but there must be adequate supervision to see that the orders, from whatever point they are given, are carried out. Also, control should not be taken away from the local foreman by giving a driver or pilot the orders, because the foreman is the man who is responsible and in charge.

It might be useful to introduce a system of incentives to the shunting staff and the drivers; perhaps a man might receive a penny for every additional wagon more than 500 moved per day. If money is to be spent on a radio system, an improved system of communication, it should be allied to some form of incentive to obtain 100% efficiency.

Mr. **J. Neale** (Post Office Engineering Department): The authors have mentioned that the P.M.G. is responsible for radio services in this country. Not only do we license civilian users, who cannot work without a licence, but we have also the problem of determining the operating frequencies. The authors say, in effect, that in time the service obtained is likely to become less satisfactory, because there will be more people using the frequencies available. I do not think this is an absolutely complete statement. Broadly speaking, it is true that the more people start using radio the more interference there will be, but we in the Post Office are not pessimistic. We think that important users will continue to get fairly good service without much interference.

On the question of the use of radio in war, I am not at the moment, owing to the security aspects, in a position to say which users of business radio would have to shut down.

There are some 200 licences in force in this country at the moment, involving the use of 1000 or more mobile stations. More and more types of people are using this system—the railways, the public utilities, the electricity people, and so on. It is a field which appears to have attraction on grounds of efficiency. I cannot, on behalf of the Post Office, make any recommendation to you that radio will be of benefit to the steel industry; our job is simply to administer it.

There are one or two small technical points to which I want to refer. Mr. Larke made a recommendation for duplex working as distinct from two-frequency simplex. So far as the Post Office is concerned, we do not mind which is used. I think the majority of private users will prefer the two-frequency simplex, one reason being the cost. Either system can be extended to a remote point in the works, to enable a foreman to use a telephone and so talk to his locomotive drivers.

The authors have not considered any uses of radio in steelworks except for the speeding up of traffic on the railway system. It is possible, especially in large works, that radio could be used for other less important applications; for example, the use of walkie-talkies by constructional and maintenance gangs or for communication from the drivers of overhead cranes to the ground. Such uses might be worth bearing in mind in the future.

Mr. **H. H. Mardon**: Mr. Neale mentioned that we have not, in the paper, considered other uses of radio in steelworks. We have thought of many uses, but in attempting to put the case before the iron and steel industry we thought it wiser to concentrate on a simple, and perhaps the most obvious, application. We felt that, if it was tried on locomotives and was successful, it might be a success elsewhere. Mr. Neale referred to another use which we had in mind, that is, for communication from the melting-shop floor to the cranes. In that connection I would also mention the possibilities of telesonic communication; telesonics may enter into

competition with radio, as being a somewhat simpler method over shorter ranges.

CORRESPONDENCE

Sir **William J. Larke** (The British Iron and Steel Federation) wrote: I would congratulate the authors on this paper, particularly as I feel that this type of investigation is very appropriate to our present problem of rapidly increasing the productivity of industry.

It is almost 50 years since I was first involved in somewhat similar problems, at which time industry was not at all receptive of the idea that the efficiency of their established processes, their sequence, and their ancillary services, really needed such inquiry; fortunately such attitude of mind has passed.

One important generalization I should have made is that the advantages that result from an investigation as complete and detailed as the authors have made on these traffic problems are not limited to the actual economies that may be effected in the traffic services, but may result in a general improvement in productivity and efficiency of the organization as a whole. These improvements, if they could be evaluated in money, would far transcend the financial economies of the improved efficiencies in the services under discussion.

I hope the authors will find it possible to continue these investigations, and those of the relation of one process to another within steelworks organizations, particularly with regard to the reduction of time in handling material and the transfer of the product from one stage of the process to another.

Mr. **A. Hunter** (United Steel Companies, Ltd.) wrote: It is not clear from the description in the paper whether there is any control of the frequency of the output from the small turbo-alternators, when these are used to supply the sets directly with A.C. Does any such control exist and, if so, what is its nature?

I would be interested to know whether the authors have encountered heavy interference of the static type when the equipment is used in areas closely built up with steel-frame buildings. It has frequently been found in the past that VHF communication is subject to interference arising from friction between corroded metal surfaces.

For equipment of this character, of a highly specialized nature and subject to rapid obsolescence, there are considerable advantages in the arrangement by which users would hire the equipment from manufacturers or their agents (*e.g.*, cinema projection equipment). The responsibility for ensuring continuity of service rests upon the hiring agent, and the incentive to manufacturers to produce equipment which will be durable and easy to service is greatly enhanced.

Lt. Col. **P. A. S. Holmes** (Transport Main Office, Royal Arsenal) wrote: It is good to know that at least one industrial transport service is receiving the scientific research which such an important technical function deserves.

I would like to know, if possible, the details of how the cost of 20–28*s.* per engine hour is arrived at, and exactly what is covered by the servicing of engines.

Also, has any investigation been made, or paper written, on the organization of steelworks transport and its traffic as a whole, covering transport policy, centralized and de-centralized control, costs accounting, and the management on the ground? Has the question of the efficiency of steelworks road transport and ancillary plant and equipment been considered? How is all this being co-ordinated with Nationalized transport?

I feel that the status and relative position of industrial transport, *vis-à-vis* production and distribution is not sufficiently appreciated and understood: it is an essential service and is very costly, especially when not properly organized and not subjected to the searching investigations discussed in the papers.

I find that the use of time recording clocks with charts is a valuable aid to checking the movement and delays of engines and road vehicles.

The question of 'planned' movement was mentioned, and it would be interesting to know when, where, and by whom this is done in the steel industry, how it is co-ordinated between sources of supply and between various works, and how it is effected by the transport department.

REPLY TO CORRESPONDENCE

Mr. **H. H. Mardon,** Mr. **M. D. Brisby,** and **Mr. H. A. Chapman** wrote in reply: Direct control of the output frequency of the turbo-generator is not incorporated, but, as the alternator is of the inductor type, the governing of the turbine speed ensures a reasonable degree of frequency control.

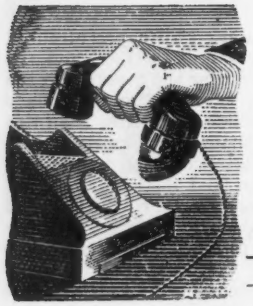
The authors have no experience of static interference with VHF radio on steelworks sites, but the noise limiters incorporated in all equipment of this type should deal effectively with sporadic bursts of static noise. If, however, the incoming interference is of the continuous, crackling variety, considerable loss of intelligibility may result.

With reference to Lt. Col. Holmes' questions, the following information, without entering into complete details of works locomotives costing, will give some indication of how costs per engine hour are derived:

Productive materials (coal, stores, etc.)	16%
Productive labour (drivers, cleaners, holidays with pay)	52%
Productive services (water, electricity, etc.)	2%
General services	2%
Maintenance service (labour and material for running repairs and renewals)	11%
Expenses direct (foreman, insurance, compensation)	12%
Expenses indirect	5%
	100%

No paper has been written, so far, covering the organization of steelworks traffic as a whole. The authors are considering the preparation of such a paper in the course of the next year.

The word 'planning' in iron and steel works traffic departments must not be interpreted too rigidly. The nature of the transport requirements is such that hour-to-hour modifications have to be made. Certain general and routine services, such as the removal and lifting of refuse, can, however, be scheduled. Where certain departments require a fixed tonnage of materials over long periods, the marshalling and handling of these wagons can also be time-tabled.



NEWS

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Changes on Council

The following have accepted invitations to serve as Honorary Members of Council:

Mr. **G. B. Thomas** (Cargo Fleet Iron Co., Ltd.) during his period of office as President of the Cleveland Institution of Engineers (to succeed Mr. E. T. Judge).

Mr. **J. H. Steel** (Richard Thomas and Baldwins Ltd.) during his period of office as Chairman of the Ebbw Vale Metallurgical Society (to succeed Mr. R. C. Powell).

Mr. **H. Edwards,** during his period of office as President of the Liverpool Metallurgical Society (to succeed Dr. S. J. Kennett).

Mr. **K. H. Wright** (C. Akrill and Co., Ltd.) during his period of office as President of the Staffordshire Iron and Steel Institute (to succeed Dr. E. Marks).

Symposium on High-Temperature Steels and Alloys for Gas Turbines

Owing to unavoidable delay in the printing of advance copies of the papers, the Symposium and the Fifth Hatfield Memorial Lecture had to be postponed from the date originally proposed in the autumn of 1950. The Council of The Iron and Steel Institute regret any inconvenience that may have been caused by the change of date.

The Symposium will now take place on **Wednesday** and **Thursday, 21st** and **22nd February, 1951,** in the Lecture Theatre of The Institution of Civil Engineers, Great George Street, London, S.W.1. Non-members of The Iron and Steel Institute will be welcome at the Meetings and functions and to contribute to the discussions.

The Sessions will begin at 10.0 A.M. and 2.30 P.M. on each day.

Buffet Luncheons will be available from 1.0 to 2.30 P.M. in the South Reading Room of The Institution of Civil Engineers on both days.

A Dinner for those attending the Symposium will be held at the Hyde Park Hotel, Knightsbridge, London, S.W.1, on Wednesday, 21st February, 1951, at 7.0 for 7.30 P.M.

The detailed programme is as follows:

Wednesday, 21st February, 1951

Morning Session

10.0 A.M.—Opening remarks from the Chairman.

10.5 A.M.—Outline of the purpose of the Symposium by D. A. Oliver, Chairman of the Organizing Committee.

10.10 A.M.—Introduction—"A Survey of the Development of Creep-Resisting Alloys," by N. P. Allen.

10.25 A.M.—Discussion on the papers in Group III, "Supplier Aspects." Rapporteur, Dr. H. Sutton (Ministry of Supply).

1.0 P.M.—Buffet Luncheon in the South Reading Room.

Afternoon Session

2.30 P.M.—Discussion on the papers in Group V, "Special Casting Techniques." Rapporteur, Dr. T. A. Taylor (National Gas Turbine Establishment).

3.45 P.M.—Discussion on the papers in Group VI, "Welding and Machinability Aspects." Rapporteur, Dr. E. C. Rollason (Murex Welding Processes, Ltd.).

7.0 for 7.30 P.M.—Dinner for Symposium participants at the Hyde Park Hotel, Knightsbridge, London, S.W.1.

Thursday, 22nd February, 1951

Morning Session

10.0 A.M.—Discussion on the papers in Group VII, "Special Blade Materials." Rapporteur, Professor G. Wesley Austin (Cambridge University).

11.30 A.M.—Discussion on the papers in Group IV, "Performance Aspects: Scaling and Fatigue at Elevated Temperatures." Rapporteur, Mr. D. G. Sopwith (National Physical Laboratory).

1.0 P.M.—Buffet Luncheon in the South Reading Room.

Afternoon Session

2.30 P.M.—Joint Discussion on the papers in Group II, "User Aspects," and Group VIII, "Research and Future Needs." Rapporteur, Mr. Hayne Constant, F.R.S. (Director, National Gas Turbine Establishment).

The full list of papers to be presented at the Symposium was published in the September, 1950, issue of the *Journal* (p. 89).

Admission—There will be no Registration Fee for the Lecture or the Symposium, but intending participants are requested to apply for cards of admission.

The Papers—The papers presented at the Symposium and the discussion during the Meeting will be issued as a single bound volume (No. 43 in the Special Report Series of The Iron and Steel Institute), the published price of which will be £3 3*s.* 0*d.* (post free). Orders received before the Meeting, if accompanied by a remittance, will be supplied at the reduced rate of £2 2*s.* 0*d.* (post free), and those who purchase a volume beforehand will be provided with a set of advance copies of the papers without extra charge. Advance copies will not be supplied separately; and not more than one set of advance copies will be supplied in respect of each bound volume ordered.

Buffet Luncheon—The charge for the Buffet Luncheons on the two Meeting days will be 4*s.* 0*d.* per person per day.

Dinner—The price of tickets for the Dinner on the Wednesday will be £1 5*s.* 0*d.* This will include gratuities but not drinks.

Fifth Hatfield Memorial Lecture

The Fifth Hatfield Memorial Lecture, on "Turbine Problems in the Development of the Whittle Engine," will be delivered by Air Commodore Sir Frank Whittle, K.B.E., C.B., M.A., D.Sc., F.R.S., on the evening of **Tuesday, 20th February, 1951,** at 8.30 P.M. in the York Hall, Caxton Hall, Caxton Street, London, S.W.1.

Admission will be by ticket, for which application should be made to the Secretary of The Iron and Steel Institute.

Annual General Meeting, 1951

The Annual General Meeting of the Institute will be held in London from **30th May** to **1st June, 1951.** A Dinner for those taking part in the Meeting will be held at the Dorchester Hotel on Wednesday evening, 30th May.

NEWS OF MEMBERS

▶ Mr. E. J. ATTREE has left the Plant Engineering Division of the British Iron and Steel Research Association to take up an appointment in the Engineering Department of Vauxhall Motors, Ltd.

▶ Mr. V. T. BALASUBRAMANIAN is now on the staff of Messrs. Hepworth and Grandage, Ltd, Bradford.

▶ Mr. A. C. BEARD, Technical Representative of The United Steel Companies, Ltd., in Argentina, has returned to the United Kingdom and will be based in the Companies' Export Department in London.

▶ Mr. M. G. COCKCROFT has taken up an appointment as a research fellow at Birmingham University.

▶ Mr. J. J. CORDIANO has left the Buel Metals Co. to take up an appointment as Quality Control Engineer with the U.S. Metals Refining Co., U.S.A.

▶ Mr. D. E. DAVIES has graduated from Cambridge University and is carrying out research work in the Corrosion Section of the Department of Metallurgy, Cambridge University, under Dr. U. R. Evans.

▶ Mr. F. DEVINE has been awarded the B.Sc. degree of Leeds University, and has taken up an appointment as metallurgist with Messrs. W. and T. Avery, Ltd., Birmingham.

▶ Mr. I. GEORGE is at the Carnegie Institute of Technology, Pittsburgh, taking a post-graduate course of study in metallurgy.

▶ Dr. J. GÖRRISSEN, President of the Norwegian Metallurgical Society, has been awarded the King's Medal for Courage in the Cause of Freedom. The Medal was bestowed on 20th September, 1950, by Sir Laurence Collier, British Ambassador in Oslo.

Obituary

Mr. H. BOSTEM, Director and General Manager of the Société Anonyme d'Ougrée-Marihaye, on 27th July, 1950.

Mr. J. E. D. SPEAKMAN, Joint Managing Director of Colliery Engineering, Ltd., on 27th August, 1950.

CONTRIBUTORS TO THE JOURNAL

C. G. Carlsson—Chief Metallurgist and Assistant Director of the Metallografiska Institutet, Stockholm. Mr. Carlsson was born in Sweden in 1911 and graduated in metallurgy from the Royal Technical University of Stockholm in 1936. He worked as a research assistant to Professor Hultgren from 1936–37, followed by five months at the Royal School of Mines, London, during which time he was engaged on research work.

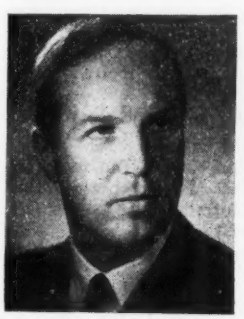
He returned to Sweden in 1938 as an assistant at the Technical Bureau of Jernkontoret. Two years later he joined the staff of the Metallografiska Institutet as research metallurgist. He was later appointed to his present position.

Mr. Carlsson spent four months in the U.S.A. in 1948. He has been a member of the Jernkontorets' Research Committee for the heat-treating and testing of steel since 1948 and has been Chairman of the Metallografiska Institutet's Committee on Emission Spectroscopy since its formation in 1947.

J. T. M. Yü, B.E.—Research Metallurgist at the Metallografiska Institutet, Stockholm. Mr. Yü obtained the B.E. degree from the mining and metallurgical department of the National University of Yunnan in 1943, and was appointed Assistant Professor in the same department in charge of the physical geology and rock and rock mineral laboratory. He was later employed as an engineer at the Yunnan Iron and Steel Works and at the Ta Tu Kou Iron and Steel Works, Chungking. Mr. Yü became Assistant Professor in the National University of Communications, Shanghai, and was subsequently awarded a National Scholarship which enabled him to take a course of study as a special student at the Royal University of Technology, Stockholm. He was later appointed to his present position where he is in charge of spectrographic slag analysis and the spectrographic analysis of non-metallic substances such as ores.

A. Oldfield—A member of the Spectrographic Laboratory, Brown-Firth Research Laboratories, Sheffield. Mr. Oldfield joined the laboratory staff in 1939, and after serving in the Royal Navy during the last war, he resumed duties in the Spectrographic Laboratory. Since 1947, he has been chiefly engaged in research and development work.

H. Kitchen—A member of the Spectrographic Laboratory, Brown-Firth Research Laboratories, Sheffield. Mr. Kitchen joined the laboratory staff in 1942 and subsequently served with the Airborne Division. He resumed work in the Spectrographic Laboratory at the end of the war.



C. G. Carlsson

J. T. M. Yü

A. Oldfield

H. Kitchen

C. C. Earley, B.Sc.—Research Worker in the Metallurgy Division of the National Physical Laboratory, Teddington. Mr. Earley graduated in Metallurgy at Birmingham University in 1945. He spent one year in the Metallurgy Division of the Royal Aircraft Establishment, Farnborough, before taking up his present appointment with the N.P.L. where he is engaged on research into the constitution and transformation characteristics of iron alloys.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

35th Steelmaking Conference

The 35th Steelmaking Conference was held at Ashorne Hill on 27th and 28th, September, 1950, and in spite of its rather specialized subject, automatic control of open-hearth furnaces, the attendance was almost a record one. The Conference opened with two very full accounts, given by open-hearth managers, of their experiences with automatically controlled furnaces, in one case using a mixed gas firing and in the other oil firing. On the following day a special exhibition of instruments and devices which had been arranged by the instrument manufacturers, was visited. Six short reports were later given by other users of automatic control. The final session, in which problems of automatic control were discussed, gave manufacturers of these systems an opportunity to comment on points raised earlier, and a very useful discussion ensued.

Physics Laboratories

The British Iron and Steel Research Association held Open Days at their Battersea Physics Laboratories on November 9th and 10th, 1950, to mark the third anniversary of the official opening of the Laboratories by Lord Rayleigh in October, 1947.

Representative examples of the work of each Section were exhibited. In the General Physics Section was shown the laboratory apparatus built for experimental work on the continuous casting of steel. Various methods of investigating the high-temperature properties of steel were displayed, including new X-ray methods for the study of transformations. Instruments developed by the Instrument Section were exhibited, and also a method of measuring the stresses in furnace roofs. Exhibits in the Aerodynamics Section included models of double tuyeres, and of a soaking pit. Also shown was equipment for measuring temperature and radiation, in particular for the temperature measurement of liquid steel, and for investigating the luminous radiation from a flame.

During the morning and afternoon of both days a 30-min. film was shown, of gas- and oil-fired furnace flames, the blowing of a Bessemer converter, and the mixing patterns produced when jets of air and liquid strike the surface of a liquid.

AFFILIATED LOCAL SOCIETIES

Sheffield Society of Engineers and Metallurgists

The Council of the Sheffield Society of Engineers and Metallurgists have issued a cordial invitation to local members of The Iron and Steel Institute to be present at the following General Meetings, which will be held in the Royal Victoria Station Hotel, Sheffield, at 6.15 P.M. :

18TH DEC. 1950—"*Some Technical and Economic Aspects of Industrial Research*," by D. A. Oliver.

19TH FEB. 1951—"*Some Aspects of Modern Steelmaking*," by A. Robinson.

The President of the Society, Professor H. W. Swift, will be in the Chair.

Ebbw Vale Metallurgical Society

A Joint Meeting of the Ebbw Vale Metallurgical Society and the Engineers Group of The Iron and Steel Institute will be held on Thursday, 14th December, 1950, at 7.15 P.M. in the Lecture Room, Messrs. Richard Thomas and Baldwins, Ltd., Ebbw Vale, Mon. Mr. J. H. Steele, Chairman of the Society, will preside.

Mr. G. Campbell, of Messrs. Richard Thomas and Baldwins, Ltd., will give a lecture on "Civil Engineering."

The following Meetings have been arranged for 1951 :

1ST FEB.—"*The Properties Required for Various Forming Operations*," by G. Murray.

15TH MAR.—(Joint Meeting with The Iron and Steel Institute). "*Some Metallographic Aspects of the Deformation of Iron*," by H. O'Neill.

Both Meetings will be held in the Lecture Room, Messrs. Richard Thomas and Baldwins, Ltd., Ebbw Vale, at 7.15 P.M.

MEMOIRS

Gerald W. Allott, died on the 14th August, 1950. He entered the drawing office of Messrs. Newton Chambers and Co., Ltd., in 1900, and remained with the Company until his retirement in 1949. At the time of his retirement, Mr. Allot was General Sales Manager of the Heavy Constructional Division, and during his 49 years of service, he represented the Company abroad on a number of occasions. He also carried out valuable liaison work with various trade associations in the foundry and constructional engineering industries.

Mr. Allot was elected a Member of The Iron and Steel Institute in 1936.

Henri Bostem, Director and General Manager of the Société Anonyme d'Ougrée-Marihaye, died on 27th July, 1950. He was born in Belgium on 5th February, 1898, and was awarded the certificate of Ingénieur Civil des Mines by the University of Mons in 1922.

M. Bostem joined the staff of the Société Anonyme d'Ougrée-Marihaye as an engineer in 1924. In 1931 he became Superintendent, Chief Engineer in 1937, and Manager of the Metallurgical Works in 1941. Four years later he was appointed Manager of the Company. He became General Manager in 1948 and, while retaining his position as General Manager, M. Bostem was this year appointed Director.

He was elected a Member of The Iron and Steel Institute in 1938, and was also a member of the Association des Ingénieurs de la Faculté Polytechnique de Mons and of the Association of Iron and Steel Engineers (U.S.A.) M. Bostem was an Honorary Member of the Association des Ingénieurs sortis de l'Ecole de Liége.

Harold G. Darling, Chairman of Directors of the Broken Hill Proprietary Co., Ltd., and Australian Iron and Steel, Ltd., died on 26th January, 1950. He was born in 1885 and was educated at Prince Alfred College, Adelaide. At the age of eighteen he entered his father's firm, John Darling and Son, grain merchants at Adelaide, and took over the management of the firm after his father's death in 1914.

In the same year he was appointed to the Board of Directors of the Broken Hill Proprietary Company, on

which he served for 35 years, being Chairman for the past 26 years. In 1920 he visited branches of the steel industry in England, America, and on the Continent, to study iron and steel plants and procedures.

Mr. Darling played a prominent part in the development of the Australian steel industry, and after the merger of the Broken Hill Proprietary Co. and Australian Iron and Steel, Ltd., in October, 1935, he played an important part in the modernization and extension of the Kembla plant of Australian Iron and Steel, Ltd. He also took a leading part in the formation of Commonwealth Aircraft Corporation Pty., Ltd., of which he became Chairman of Directors. In 1942 he was appointed a member of the Aircraft Advisory Board by the Commonwealth Government. He was a director of a number of other companies in Australia.

Mr. Darling was elected a Member of The Iron and Steel Institute in 1921.

Horace W. Gillett died on 30th March, 1950. In 1929 he was appointed first director of the Battelle Memorial Institute, Columbus, Ohio, a position which he held until 1934. He was elected a Member of The Iron and Steel Institute in 1930 and was a member of the Institute of Metals. He retired from the position of chief technical adviser to the Institute of Metals in 1949.

Roosevelt Griffiths, M.Sc., died on 24th June, 1950. Mr. Griffiths was born in 1903 at Pontypridd and was educated at Pontypridd Secondary School and at University College, Swansea, where he obtained the B.Sc. degree in metallurgy.

In 1926, after a short period on the staff of Robert Gordon's College, Aberdeen, he returned to Swansea to undertake research work under Professor C. A. Edwards. He was appointed an assistant lecturer in 1927, lecturer in 1930, and first lecturer in 1940. In 1931 he was awarded the M.Sc. degree.

Mr. Griffiths was elected a Member of The Iron and Steel Institute in 1938 and at the time of his death was an Honorary Member of Council. He was a Founder Member and Member of Council of the Institution of Metallurgists, and a Member of Council and a Vice-President of the local section of the Institute of Metals and of the Swansea Metallurgical Society. He was awarded a Carnegie Scholarship by The Iron and Steel Institute in 1936 and in 1938, to carry on investigations on the oxidation and scaling of iron and steel and had published several papers on the subject. Mr. Griffiths was the author of "Thermostats and Temperature Regulating Instruments" and at the time of his death was writing a book on "Measurement of Thermal Changes in Alloys."

Mr. Griffiths was also Joint Managing Director of Messrs. Rees and Kirby, a Swansea firm of structural engineers.

Aubrey John Hudson, M.B.E., died on 5th August, 1949. He obtained the B.Sc.(Eng.) degree of the University of Cape Town in 1930 and was employed by Messrs. J. and R. Niven, Johannesburg, from 1931–32. In 1932 he started to serve a three-year pupilage on the South African Railways and Harbours. At the end of this time he was appointed assistant engineer of the Railways Workshops, Pretoria. In 1937, Mr. Hudson was appointed assistant locomotive superintendent of the Natal System, South African Railways and Harbours, and two years later became assistant mechanical engineer at their Pietermaritzburg workshops.

During the 2nd World War, Mr. Hudson served in the South African Engineer Corps and at the end of hostilities he returned to South African Railways and Harbours as assistant mechanical engineer at their Pretoria workshops. In March 1946 he resigned this post to take up an appointment as Technical Manager with the South African Farm Implement Manufacturers, Ltd.

Mr Hudson was elected a Member of The Iron and Steel Institute in 1947 and was also a member of the Institution of Production Engineers. He was awarded the M.B.E. for services with the Eighth Army from November, 1942 to April, 1943.

John Edwin Rippon, M.Met., died on 14th April, 1950. He was educated at Sheffield University, graduating in Metallurgy in 1915, and was awarded the Mappin Medal. A year later he obtained the M.Met. degree.

From 1918 to 1930 Mr. Rippon was Research Metallurgist at the Manchester Works of the original firm of Sir W. G. Armstrong Whitworth and Co., Ltd. With the formation of the English Steel Corporation, Ltd., in 1930, he was appointed to be in charge of the Heat Treatment Section of the Small Tools Department, also acting in an advisory capacity on the manufacture of special tool steels at the Openshaw Works, Manchester. In 1938 he became Manager of the Magnet Department and in 1946 he was appointed Manager of the Special Steels Department manufacturing all qualities of high-speed and tool steel.

Mr. Rippon was elected a Member of The Iron and Steel Institute in 1919.

David E. Roberts, M.I.Mech.E., died on 21st July, 1950. He was educated at Christ College, Brecon, and attended evening classes run in connection with University College, Cardiff, during his apprenticeship in the Engineering Department of the Rhymney Iron Company. In 1890 he became head draughtsman.

In 1891 Mr. Roberts was appointed Assistant Engineer in the steelmaking department of the Dowlais Iron Company and six years later was appointed Engineer in the same department. In 1902 he was appointed Chief Engineer with the same Company and became Consulting Engineer in the following year.

During World War I Mr. Roberts was Managing Director of the Cardiff National Shell Factory and Technical Adviser to the Ministry of Munitions on iron and steel works extensions.

Mr. Roberts was elected a Member of The Iron and Steel Institute in 1891. He was a Past-President of the Institution of Mechanical Engineers.

John Edward Davan Speakman, B.Sc., Joint Managing Director of Colliery Engineering, Ltd., died on 28th August, 1950. After obtaining the B.Sc.(Eng.) degree of the University of London and a diploma of the Borough Polytechnic with distinction in Engineering, he was employed in drawing offices and engineering shops. During the First World War he served with the R.A.F. Mr. Speakman later joined the staff of H.M. Fuel Research Station, Greenwich, as Assistant Engineer.

Three years later, in 1925, he joined the staff of Dr. R. Lessing, and was engaged on the design and construction of coal-cleaning plant. When Messrs. Newton Chambers and Co., Ltd., took over the rights under the Lessing process in 1930, Mr. Speakman continued the work concerned with the construction of new plant.

In 1934 he joined Colliery Engineering, Ltd., who acquired the Lessing and other processes, as their Northern Representative at Newcastle. During World War II he joined the staff of the Head Office in Sheffield and was concerned principally with the Sales and Contracts side of the plants.

Mr. Speakman was later appointed Special Director of the Company and earlier this year he became Joint Managing Director.

Mr. Speakman was elected a Member of The Iron and Steel Institute in 1948.

Slater Willis, F.C.I.S., died on 9th August, 1950. He was born in Manchester on 29th April, 1874, but when a few years old moved to Sheffield, where he was

educated. He started work with Messrs. Kittel, Willish and Co. and in 1898 went to Canada for this firm on a scheme connected with gold mining. The following year Mr. Willis joined the Tinsley Rolling Mills Co., Ltd., Sheffield, as Secretary. He became a Director in 1915, Managing Director in 1930, and Chairman in 1936.

Mr. Willis had been a Member of The Iron and Steel Institute since 1938, and was a member of the Sheffield Trades Technical Society, a member of the Society of Sheffield Engineers and Metallurgists, and a Governor of Sheffield University. He was also a Freeman of the Cutlers' Company of Hallamshire and a Past-President of the Sheffield Chamber of Commerce.

Colonel **Sir W. Charles Wright, Bart., G.B.E., C.B.**, Past-President of The Iron and Steel Institute, died on 14th August, 1950. He was born in 1876 and succeeded to the baronetcy in 1926. During the First World War he was Controller of Iron and Steel Production at the Ministry of Munitions, and he held the same position in the Ministry of Supply during World War II.

Sir Charles was Chairman and Managing Director of Baldwins, Ltd., and on that Company's merger in 1945 with Richard Thomas and Co., Ltd., he became Chairman of Baldwins (Holdings), Ltd., and Director of Richard Thomas and Baldwins, Ltd. He was Chairman and Managing Director of Guest Keen Baldwins Iron and Steel Co., Ltd., until 1947, when he retired from these offices but remained on the Board. He was also a Director of the Great Western Railway Company (until its nationalization), African Metals Corporation, Ltd., Elba Tinplate Co., Ltd., The Oxfordshire Ironstone Co., Ltd., Shell Transport and Trading Co., Ltd., Venezuelan Oil Concessions Ltd., and of other companies. He retired from practically all his Directorships in March, 1949.

Sir Charles was created a C.B. in 1918, a K.B.E. in 1920, and a G.B.E. in 1943. He was a commander of the Legion of Honour and a Commander of the Order of the Crown of Italy.

He became a Member of The Iron and Steel Institute in 1902 and was President from 1931–33. In 1937–38 he was President of the British Iron and Steel Federation.

CORRIGENDA

The Production of Steel Plates in Scotland

The following corrections should be made to the paper by J. A. Kilby (*Journal of The Iron and Steel Institute*, 1950, vol. 166, Sept., pp. 29–70):

Page 45, Table XIII, Wishaw Works, for 'universal' read 'tandem.'

Pages 56, 57, Figs. 12 and 13 should both read 'built 1884'.

DIARY

4th Dec.—THE INSTITUTE OF BRITISH FOUNDRYMEN (Sheffield Branch)—"*The Function of a Process Planning Department in a Steel Foundry*," by L. Finch—Royal Victoria Station Hotel, Sheffield, 7.30 P.M.

7th Dec.—LIVERPOOL METALLURGICAL SOCIETY—"*Research in Deep Drawing*," by Professor H. W. Swift—Electricity Service Centre, Whitechapel, Liverpool, 7.0 P.M.

7th Dec.—INSTITUTE OF METALS (Joint meeting with the Institute of British Foundrymen)—"*Modern Melting Practices*," by F. C. Evans—4 Grosvenor Gardens, London, S.W.1., 7.0 P.M.

7th Dec.—CHEMICAL ENGINEERING GROUP OF THE SOCIETY OF CHEMICAL ENGINEERING (Joint meeting with Bristol Section)—"*Carbon as a Material of Construction*," by A. W. Morrison—Bristol.

9th Dec.—SWANSEA AND DISTRICT METALLURGICAL SOCIETY (Joint meeting with The Iron and Steel Institute)—"*Ingot Defects*," by N. H. Bacon—Central Library, Swansea, 6.30 P.M.

12th Dec.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Problems in the Development of Creep-Resisting Steels*," by G. M. Gemmill—Grand Hotel, Sheffield, 7.0 P.M.

12th Dec.—THE INSTITUTE OF WELDING (Sheffield and District Branch)—"*The Welding of Gas-Turbine Steels*," by E. Bishop—College of Commerce and Technology, Pond Street, Sheffield, 7.0 P.M.

14th Dec.—EBBW VALE METALLURGICAL SOCIETY (Joint Meeting with the Engineers Group of The Iron and Steel Institute)—"*Civil Engineering*," by G. Campbell—Lecture Room, Messrs. Richard Thomas and Baldwins, Ltd., Ebbw Vale, 7.15 P.M.

15th Dec.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—"*Tube Manufacture*," by J. W. Jenkins—39 Elmbank Crescent, Glasgow, 6.45 P.M.

18th Dec.—SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—Annual General Meeting—"*Some Technical and Economic Aspects of Industrial Research*," by D. A. Oliver—Royal Victoria Station Hotel, Sheffield, 6.15 P.M.

19th Dec.—THE INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND—"*Blast-Furnace Slag Building Materials*," by T. W. Parker—39 Elmbank Crescent, Glasgow, 6.30 P.M.

TRANSLATION SERVICE

(The previous announcement was made in the November, 1950, issue of the *Journal*, p. 256.)

TRANSLATIONS AVAILABLE

No. 411 (German). F. W. WEVER and W. KOCH: "The Transformation Kinetics of Steels. The Compositions of the Reactants during the Transformation of a Chromium–Manganese Steel in the Pearlite Range." (*Archiv für das Eisenhüttenwesen*, 1950, vol. 21, May/June, pp. 143–152). (Translated by Mr. C. B. Lander and made available through the courtesy of the Development and Research Department of The Mond Nickel Co., Ltd., Birmingham).

No. 412 (German). W. KOCH: "Electrolytic Isolation of the Carbides in Alloyed and Unalloyed Steels." (*Stahl und Eisen*, 1949, vol. 69, Jan. 6, pp. 1–8).

TRANSLATIONS IN COURSE OF PREPARATION

(German). T. KOOTZ and W. OELSEN: "A Contribution to the Metallurgy of the Blast-Furnace." (*Archiv für das Eisenhüttenwesen*, 1950, vol. 21, Mar./Apr., pp. 77–88). (Translated by Dr. P. Herasymenko and made available through the courtesy of The United Steel Companies, Ltd., Research and Development Department, Stocksbridge, near Sheffield).

(Czech). P. SKULARI: "Determination of Internal Stresses of the Second Type." (*Druký Pracovní Sjezd Hornich a Hutnich Inženyrů*, 1947, May, pp. 127–144).

(German). W. JELLINGHAUS: "New Developments in the Non-Destructive Testing of Materials by Electrical and Magnetic Methods." (*Stahl und Eisen*, 1950, vol. 70, June 22, pp. 552–560; discussion, pp. 560–561).

(German). P. RÜDIGER: "Progress in the Non-Destructive Testing of Materials by Supersonics." (*Stahl und Eisen*, 1950, vol. 70, June 22, pp. 561–565; discussion, p. 565).

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

Iron Considered Geologically. V. Mendez. (Metalurgia y Electricidad, 1949, vol. 13, Dec., pp. 54–57). [In Spanish]. The situation of iron deposits is explained in relation to the mineralogical make-up of the earth. Some general remarks are made on the origin of mineral wealth and the various mineralogical zones. Iron is then considered chemically and the effects of the presence of other metals and metalloids is explained. The following minerals are briefly described: Spathic pyrites; oxides of iron and chromium; magnetite; iron pyrites; arsenical pyrites; hematite, limonite; and specular iron ore. Finally, a brief sketch is given of the Spanish iron ore deposits of Vizcaya and Asturias.—R. S.

Geology of the North-Western Coalfield. Part I—Geology of the Willow Tree District. Part II—Geology of the Willow Tree-Temi District. Part III—Geology of the Murrurundi-Temi District. F. N. Hanlon. (Journal and Proceedings of the Royal Society of New South Wales for 1947, vol. 81, Parts I–IV, pp. 280–297).

Chromite and Other Mineral Occurrences in the Tastepe District of Eskisehir, Turkey. F. Kromer. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 187, pp. 108–110: Mining Engineering, 1950, Jan.). The author describes the geology, occurrences, mining methods, and costs respecting the economically significant minerals chromite, meerschaum, and magnesite near Eskisehir in Turkey.—R. A. R.

Present Position of the Palaeozoic Iron Ores in Spain. P. H. Sampelayo. (Instituto del Hierro y del Acero, 1950, vol. 3, Jan.–Mar., pp. 23–29). [In Spanish]. The author expresses some independent ideas on the nature, occurrence, class, and texture of those siluric-devonian ores which already form the subject of advanced studies in other countries. He proposes the combination of mining and industrial data including analyses, fusibility, mechanical strength, and penetrability as a basis to the grouping of these ores in accordance with their suitability for use in the various types of furnace. The geology and origin of the Asturian ores are discussed in detail.—R. S.

A Look at the Iron Ore Situation. T. L. Joseph and E. P. Pfleider. (Blast Furnace and Steel Plant, 1949, vol. 37, Oct., pp. 1195–1198). From a study of trends in steel production in the United States the authors prophesy that (1) The overall demand will increase consistently with the growth in population. (2) The South-eastern, North-eastern, and Western States will continue to supply about the same amounts of iron ores as at present. (3) The increased steel production will involve an increase in the importation of iron ore to replace Lake Superior ores. (4) This will occur during the period of development of taconite concentration. (5) The exploitation of taconite will extend the life of the Lake Superior deposits. A growth of shipping of concentrates apart from taconite is also expected, but this will reach its maximum at, and decline after, 1960–1970, though concentration of taconite may not be at its maximum by the year 2000. The direct shipment of untreated ore is already diminishing and this form of ore will fall to 20% of the total leaving the Lake district by 2000.—J. P. S.

Mining and Metallurgy in the Republic of Dominica. F. Mota. (Metalurgia y Electricidad, 1949, vol. 13, Dec., pp. 59–60). [In Spanish]. The physical geography of the Dominican Republic is described. The iron ore deposits of Duarte province are divided into three zones extending over 100 sq. km. around the town of Hatillo. It is generally found in masses of magnetite in lenticles, dykes, and strata. Forty-three million tons have been estimated. Samples of Hatillo magnetite contain Fe 68·54%, SiO_2 1·28%, Al_2O_3 0·51%, Mn 0·16%, CaO 0·20%, TiO_2 0·04%, S 0·02%, and P 0·04%. The most important deposits can be worked open-cast. Garnierite, containing 15% of nickel, has also been found 10 km. from Hatillo, and has been estimated at two and a half million tons. This can also be surface-mined. Lignite is also available and there are hopes of petroleum developments.—R. S.

Problems and Future of Brazilian Metallurgy. A. Phillips. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, July, pp. 3–10). [In Portuguese]. The author studies the ore resources in Brazil in relation to the present industrialization and availability of trained technical personnel. He shows that the ultimate growth of the metallurgical industry depends largely on the development of an internal market and on the training of specialists. The importance of physcial metallurgy, especially in the non-ferrous field, tends to increase greatly in Brazil due to the rapid development of the fabricating industries. Brazil can occupy an important position in world production of the less common metals such as wolfram, zirconium, titanium, tantalum, and beryllium, of which she possesses considerable reserves.—R. S.

Mineral and Industrial Riches of the Free Phillipines. J. Sanz y Diaz. (Metalurgia y Electricidad, 1950, vol. 14, Jan., pp. 28–29). [In Spanish]. The attitude of Spain to the newly won independence of the Phillipines is briefly explained. The chief minerals are gold, silver, lead, zinc, copper, iron, coal, petroleum, sulphur, manganese, and asbestos. The iron mines are in the eastern and south-eastern mountain ranges of Luzon. A list of mining enterprises is given.—R. S.

ORES—MINING AND TREATMENT

The Drainage Plant of the Giraumont Iron Mines in Northern France. R. de Saint-Vaulry. (Sulzer Technical Review, 1949, No. 4, pp. 19–23). The pumping system at the Giraumont iron ore mines now comprises four Sulzer pumps to deliver 3300 gal./min. each against a manometric head of 733 ft. while running at 1480 r.p.m.; they require 915 h.p. These are equipped to deal not only with the normal seepage water but also with any occasional inrush of much greater quantities which may occur after blasting operations.—R. A. R.

Conveyor Systems in Underground Iron-Ore Mines, Lake Superior District. E. O. Binyon. (United States Bureau of Mines, 1949, Information Circular 7526).

Transportation and Handling of Iron Ore. P. L. Tietjen. (Steel, 1949, vol. 125, Dec. 19, pp. 88–96). An illustrated account is given of the transport of iron ore across the Great Lakes, with special reference to the loading and unloading equipment.—R. A. R.

Iron Mining in Vizcaya. L. Barreiro. (Boletin Mineral e Industrial, 1950, vol. 29, Jan., pp. 1–16). [In Spanish]. A short survey is given of the production of Vizcayan iron ore and exports since the record year of 1899 (6,495,000 tons). The difficulties in the way of increasing production in 1948 are then discussed. The main difficulty was labour shortage and 1000 soldiers may be sent to work in the mines (they would be paid daily rates). Output would then be increased 35% in three years. The second difficulty was restrictions in electric power.

The projects for study by a Committee for the Investigation of Spanish Iron Ores are discussed. Other items of interest reviewed are: Increases in production costs; incentives to labour and bonus systems; electric power costs; costs of calcining; and manufacture of explosives. A table is reproduced showing average daily wages, including items of social charges. Other data in the form of tables cover: Total home and export sales from the various mines in 1948; production and consumption of Vizcayan iron ores from 1876 to 1949; average price per ton from 1912 to 1948; prices c.i.f. Middlesbrough and freights from 1913 to 1935; total exports of Spanish Moroccan ores from 1914 to 1948; exports of Vizcayan ores 1878 to 1948 to various countries; exports of Spanish Moroccan ores to various countries from 1914 to 1948.—R. S.

Titanium and Iron Minerals from Black Sands in Bauxite. W. A. Calhoun. (United States Bureau of Mines, 1950, Jan., Report of Investigations 4621). This report gives the methods of conservation of valuable titanium and iron minerals in the waste products from Arkansas ores.—R. A. R.

Proposed Process for Treatment of Low-Grade Titaniferous Ores. R. T. MacMillan, J. I. Dinnin, and J. E. Conley. (United States Bureau of Mines, 1950, Jan., Report of Investigations 4638). An essentially chemical technique has been developed on a small scale for the efficient utilization of certain American titaniferous iron ores. The three main steps involved are: (1) Sintering the ore at 1050° C. with carbon and soda ash to reduce the iron to metal powder, retaining the titania in the slag; (2) separating the iron powder from the slag; and (3) decomposing the titania fraction with sulphuric acid to produce pigment and certain by-products.

R. A. R.

Experiments on Concentrating TiO_2 in Wehrlite (Titaniferous Iron Ore) Mined in Hungary. L. Visnyovszky. (Bányászati és Kohászati Lapok, 1950, vol. 5, Jan., pp. 58–67). [In Hungarian]. The author carried out experiments with the object of finding an economical process of concentrating Hungarian titaniferous ores. It is necessary to reduce the iron oxides in this ore to metallic iron to enable magnetic methods to be used. The ore has to be crushed to 8 mm. max. to obtain reduction of 65–75% of the iron content with solid carbon at 1100° C. For the concentration process the grains must be equal to or smaller than those of titanium and iron oxide crystals, *i.e.*, $\leqslant 0{\cdot}4$ mm. For magnetic separation a wet process is more suitable, because the separation of grains of less than 0·1 mm. can be carried out more efficiently than with dry separation. Separation can also be carried out by flotation. Owing to the high TiO_2 content of the product obtained the main emphasis should be on producing TiO_2. The processing should preferably be carried out by chemical methods, since separation of the iron by smelting is complicated by the presence of 50–55% TiO_2 in the slag. In a melting experiment in a crucible on concentrated ore containing 30–35% iron and 17–20% TiO_2 only 0·1 kg. of iron was obtained instead of an anticipated 0·8 kg., the remaining iron was in the slag. The temperature at the end of the process was 1580–1600° C.; in a second experiment the temperature was raised to 1650° C. and again most of the iron remained in the slag. The composition of the iron obtained in the first experiment was C 2·36%, Si 10·50%, Mn 0·65%, P 0·103%, S 0·016%, Ti 2·57%, and in the second experiment: C 1·59%, Si 13·03%, Mn 0·90%, P 0·113%, S 0·012%, Ti 2·83%. The author thinks that chemical separation processes with sulphuric acid and chlorine are likely to be successful.—E. G.

On the Theory of Correct Agglomeration of Iron Ores. P. Henry. (Hutnické Listy, 1949, vol. 4, Dec., pp. 395–398). [In Czech]. The individual phases of the agglomeration process are discussed, *e.g.*, ignition, combustion, and mixing, and their relative importance in obtaining favourable grain sizes (the optimum size being that of caviar grains) is described. The importance of moisture control is stressed. A good agglomerate is completely unoxidized and highly porous.—E. G.

Iron Ore, Its Mining, Beneficiation and Reserves. E. W. Davis. (Steel, 1949, vol. 125, Nov. 21, pp. 96–111; Nov. 28, pp. 78–84, 92; Dec. 5, pp. 122–128). The Lake Superior iron ore region has six ranges which in the peak production year of 1942 supplied the following quantities (in millions of short tons): Mesabi 70·3, Vermilion 1·9, Cuyuna 3·0, Gogebic 6·2, Marquette 6·5, Menominee 4·9. Extensive data on the production of iron ore and concentrates in this and other regions of the U.S.A. are presented and analysed. The great value of the open pits of the Mesabi range to the United States industry has been the flexibility of production which, for example, was smoothly increased from 1938 to 1942 from 13 to 70 million tons by employing more men and more shovels. Such flexibility is impossible with mined ore. It is estimated that the reserves at Mesabi are sufficient to last barely ten years at the present high rates of production, and the author suggests that, to avert an ore shortage, large plants will have to be erected to process taconite and other lean ores, and that existing steelworks will have to be provided with facilities for importing 10 to 20 million tons of ore per annum.—R. A. R.

Electrical Equipment for the Modern Steel Plant. Part V. Sintering Plants. E. A. E. Rich. (Blast Furnace and Steel Plant, 1949, vol. 37, Oct., pp. 1205–1212, 1256–1257). The distribution of electric power to the numerous motors of a modern sintering plant and the means installed for controlling these are fully described.—J. P. S.

Sintering and Benefication of Iron Ores in the Works of the Altos Hornos de Vizcaya S.A. F. Millan and F. Barbadillo. (Instituto del Hierro y del Acero, 1950, vol. 3., Jan.–Mar., pp. 47–53). [In Spanish]. The necessity for ore preparation is emphasized, especially as 80% of the Vizcaya-Santander ores consist of carbonates. More than 300 sintering trials have shown that up to 85% of the sulphur can be removed. The improvement in the quality of the pig iron due to burden preparation will be even more important than the increase in production and the saving in coke.

At present, the Vizcayan blast-furnaces are being charged with ore as received from the mines. There is no uniformity in physical or chemical properties and 40 to 50 types of ore are being used. In the Sestao blast-furnaces it is current practice to vary the burden as much as six or seven times a day, thus eliminating the possibility of slag control.

Estimates of improvement in output and quality when the projected beneficiation plant is installed, are discussed. A drawing of the proposed preparation plant, including bedding equipment, to be laid down on the left bank of the Bilbao river, is given. These installations will consist of stocking, drying, crushing, screening, bedding, and sintering plants. Two Dwight-Lloyd machines will be installed with 50 sq. m. suction surface and a sintering capacity of 1000 tons/day.—R. S.

Sintering Trials with Iron Ores in the Pilot Plant of the Duro Felguera Metallurgical Society. M. Aybar Gallego. Boletin Mineral e Industrial, 1950, vol. 29, Jan., pp. 17–22). [In Spanish]. The plant, built in 1945, consists of ore stocking yard, mixer, charging equipment, sinter pans (Greenawalt) with 2·2 sq.m. suction surface, ignition, fans, and gas-holder. The first trials in October, 1945, were with a mixture of wet Llumeres ore fines and 8% of powdered coke (950 kg. per pan).

Less coke was added in subsequent trials to avoid excessive slagging. The analysis of the Llumeres fines was: gangue 14·25%, SiO_2 13·00%, total iron 48·33%, Mn 0·12%, CaO 1·52%, MgO 0·35%, Al_2O_3 4·61%, P 0·60%, S 0·075%, CO_2 1·95%, combined water 1·98%, ferrous oxide 4·35%, ferric oxide 43·98%, moisture 3·70%

The mixture consisted of 77% Llumeres fines, 19% returned fines, and 4% coke dust. Maxmum humidity was 5%. Sintering time was 20 to 25 min. A sample of the finished sinter had the following analysis: gangue 22·91%, SiO_2 15·63%, total iron 49·36%, Mn 0·17%, CaO 4·55%, MgO nil, Al_2O_3 8·74%, P 0·55%, S 0·008%, ferrous oxide 1·75%, ferric oxide 47·61%, water 0·45%. Details are given of the coke and flue dust used. The author also describes sintering trials with a high-sulphur (0·53%) manganiferous (5·4% Mn) ore from Cartagena with a lead content of 1·23% and with other Spanish and Moroccan ores—R. S.

The Monlevade Sintering Plant. F. J. Pinto de Souza. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, Oct., pp. 552–573). [In Portuguese]. The Companhia Siderurgica Belgo Mineira S.A. recently began the sintering of iron ores for their Monlevade blast-furnace. The 300-ton per day Greenawalt plant is described. The ore used came from the Andrade deposits (perhaps the most intensively studied in Brazil). These ores consist of: hematite and compact itabirite (67% Fe, 0·015 to 0·40% P); jacutinga (a rich, fine ore similar to the first); canga (61–63% Fe, 0·08–0·30% P); lower grade ores (40–60% Fe, up to 40% SiO_2). The Monlevade furnaces use 50% canga with hematites or hard itabirites.—R. S.

The "AIB-Holmberg" Process for Sintering Iron Ores. A. Holmberg. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, Oct., pp. 37–46). [In Portuguese]. The author considers the possibilities of using this system (already finding wide application in Sweden) to increase blast-furnace output in Brazil and to economize in the use of charcoal for reduction. An illustrated description of this 'stationary' system is given.—R. S.

Some Factors Influencing the Sintering of Iron Ores. T. D. De Souza Santos. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, Jan., pp. 57–67). [In Portuguese]. Amongst the most important variables influencing the sintering of iron ores are: Porosity of the charge; percentage of solid fuel; humidity and percentage of returned fines; and materials resulting from the fragmentation of the sinter which form part of the charge. Having carried out a large number of sintering tests on Brazilian ores, the author concludes that the efficiency of the operation depends mainly on the specific volume of the charge and the proportion of returned fines, and that the intensity of sintering is related to the amount of fuel used.

The pilot plant used by the Division of Metallurgy of the Technological Research Institute (I.P.T.) of São Paulo, which was built by the author, is illustrated.—R. S.

Development of Sintering and Use of Iron Ores in Sweden. E. Brauns. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Jan., pp. 29–35). [In Portuguese]. Sintering of iron ores began in Sweden in 1916. An increasing proportion of sinter is used in blast-furnaces. Swedish sinter output now exceeds 1,200,000 tons/annum. The author discusses the question of the proportion of sinter in the burden (present Swedish practice is to use about 100%). Charcoal consumption has dropped from 930 kg./ton in 1923 to 675 kg./ton of iron today.—R. S.

FUEL—PREPARATION, PROPERTIES, AND USES

Low Pressure Flames and Flame Propagation. A. G. Gaydon and H. G. Wolfhard. (Fuel, 1950, vol. 29, Jan., pp. 15–19). The experimental technique for running premixed flames down to pressures of a few millimetres is described. Measurements on the limits of flame stability for hydrocarbon flames are reported, and measurements of burning velocities down to very low pressures are given. For flames with oxygen, the burning velocity is nearly independent of pressure. It is shown that the thickness of the reaction zone increases at low pressure and is always nearly equal to the distance which free hydrogen atoms from the hot burnt gases may diffuse back against the gas stream. The importance of the diffusion of hydrogen atoms in propagating flames through pre-mixed gases is pointed out.

Propagation of Flame. J. W. Linnet. (Fuel, 1950, vol. 29, Jan., pp. 13–15). The importance of the measurement of flame velocities in attempting to assess the relative importance of thermal conduction and radical diffusion in the propagation of flames is pointed out. The methods that the author has used to determine flame velocities are briefly described; they are the burner and the soap bubble methods. A few examples are given of the usefulness of the results in obtaining information about the mechanism of flame propagation.

The Science of Flames and Furnaces. M. W. Thring. (Iron and Coal Trades Review, 1949, vol. 159, Aug. 19, pp. 457–465; Aug. 26, pp. 525–531; Sept. 9, pp. 615–621; Sept. 16, pp. 677–682; Sept. 30, pp. 785–794; Oct. 7, pp. 839–846; Oct. 28, pp. 989–996; Nov. 4, pp. 1057–1063; Nov. 18, pp. 1171–1176, 1178; Nov. 25, pp. 1231–1239; Dec. 30, pp. 1495–1505; 1950, vol. 160, Jan. 6, pp. 21–30; Jan. 13, pp. 79–82; Feb. 3, pp. 251–258; Feb. 17, pp. 387–390; Mar. 10, pp. 545–554; Mar. 24, pp. 685–690). In this series of articles on the science of flames and furnaces, part I (in two instalments) discusses present-day industrial furnaces. Part II (in two instalments) deals with the laws of thermodynamics and efficiency of heating and their application to furnaces, the use of Sankey diagrams in furnace design to represent the heat balance of furnace systems, the control of furnaces using preheated fuel, and atmosphere control. An ideal furnace as specified by thermodynamics is described. Part III (in two instalments) deals with chemical reactions which result in the heating of furnaces, the extent and direction to which they can be expected to spread and the energy released, the speed of combustion of diffusion flames and solid fuels, reactions occurring in fuel beds and pulverized fuel-firing, and methods of control of combustion. Part IV (four instalments) deals with the transfer of heat of the flame to the charge. Gas-temperature measuring units are described, and theoretical considerations of the flow of gases are reviewed. In discussing transfer by radiation the author shows how theoretical results can be applied in practice and what variables have to be considered. Heat transfer by convection and the effect of muffles when using parallel and counterflow heating are discussed and formulæ are derived giving the heat transfer from a flame through a muffle wall. Methods of measuring radiation from furnace flames, heat losses through the furnace skin, and the use of these results to estimate internal wall temperatures are described. Heat losses due to conduction through solid walls, open doors, water cooling, and gas leakage, are estimated. Finally, heat transfer in the unsteady state, including the heating of a charge in a batch-type furnace and heat transfer in regenerators, is considered. Part V (three instalments) is concerned with the measurement of the flow of gases and factors affecting the volume of flow. The turbulent and streamline flow of gases and sources of aeromotive forces such as injectors and fans are reviewed. Formulæ are derived for giving the pressure differences caused by resistances set up in the circuit, and for calculating volume flow from pressure differentials across such restrictions as orifices and venturis. The importance of inner structure of gas flow, *e.g.*, eddies and stagnant pockets, is discussed. The effects of buoyancy and of mixing two gas streams on flow distribution are considered. Experimental methods are suggested for studying sub-division of flow and include the use of radon gas and of models. Part VI (two instalments) deals with the importance and behaviour of various refractory materials used and their part in ideal furnace construction. Tests for refractories are described and the properties of some common refractories are given. The principles of furnace wall and roof construction are outlined. Finally Part VII (two instalments) considers the use of probes and quenching methods in the diagnosis of furnaces and an attempt is made to relate the data obtained to the theoretical output of the furnace. The use of derived formulæ in designing modifications of existing furnaces is discussed. Factors for increasing effioiency, calculation of probable performances, deduction of heat transfer, and combustion coefficients are explained, while general laws governing combustion-heated furnaces are given.—J. C. R.

Nomograms in the Design of Heat Transfer Equipment. J. H. Ellinger. (Industrial Chemist, 1950, vol. 26, Jan., pp. 7–12; Mar., pp. 99–108). In the first part general considerations in the design of nomograms are briefly discussed and a method especially convenient for the production of

more complex nomograms is then described by a typical series of calculations. In the second part the basic formulæ are given for which nomograms have been designed, together with the constants to be used when applying the general formulæ to specific cases. Four nomograms are given which are designed to enable the heat-transfer calculations for designing tubular heat exchangers to be evaluated in a simple manner.—R. A. R.

Controls for Industrial Furnaces. C. S. Darling. (Power and Works Engineering, 1950, vol. 45, Jan., pp. 14–19). The control of industrial furnaces and gas producers is discussed and it is shown that saving fuel is not the sole object since, in some cases, the difference in cost between one fuel and another may be insignificant when considering metal losses.
R. A. R.

Cleaning Fine Coals. Recent Developments in Holland. J. R. Prentice. (Iron and Coal Trades Review, 1950, vol. 160, Jan. 20, pp. 125–130). A description is presented of coal-washing and preparation practice at four Netherlands State colleries. At the Emma mine a cyclone washer with five cyclones is installed and deals with 50 tons of coal (0·5 to 8 mm.) per hr. At the Maurits mine a Dutch froth-flotation plant called "Kleinbentink" is installed. A brief note is included on the research activities of a central laboratory and a central experimental station.—J. C. R.

Cyclone Thickener Applications in the Coal Industry. M. G. Driessen and H. E. Criner. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 187, pp. 102–107: Mining Engineering, 1950, Jan.). There are two important applications of the cyclone thickener in wet washing plants: Clarification of the washery water and recovery of fine coal from the plant bleed water. The authors show that it is possible with this equipment to remove all particles, including the very finest, from the circulating water, thus obtaining a closed water system, as well as to reduce the ash content of the solids in the bleed water.
R. A. R.

Application of BM-AGA Carbonization Test Results to Byproduct Practice. C. H. Flickinger and J. P. Graham. (United States Bureau of Mines, 1949, Technical Paper 726, pp. 51–55). The Bureau of Mines laboratory has recently completed BM-AGA carbonization tests (Bureau of Mines/American Gas Association) on most of the high and medium-volatile coals used at six coke-oven plants of the Republic Steel Corp. Some reasons are given for differences between actual plant yields and the results of the above tests.—R. A. R.

The Testing of Coal for Coke Making. (British Coke Research Association, 1948, July, Technical Paper No. 1). The present report (Interim Report No. 1 to the Research Committee of B.C.R.A.) is now recommended to the industry for general adoption to ensure that methods of sampling, analysis and testing conform to suitable standards. The methods described include the determinations of moisture, ash, volatile matter and sulphur, in coal and coke, and of the crucible swelling number of coal.—R. A. R.

Carbonizing Properties of Lower Banner Coal from No. 56 Mine, Dante, Russell County, Va. J. D. Davis, D. A. Reynolds, R. E. Brewer, W. H. Ode, B. W. Naugle, and D. E. Wolfson. (United States Bureau of Mines, 1949, Technical Paper 720).

Carbonizing Properties of Thick Freeport and Pittsburgh Coals from Pennsylvania, Elkhorn Coal from Kentucky, and America and Mary Lee Coals from Alabama. J. D. Davis, D. A. Reynolds, B. W. Naugle, D. E. Wolfson, and G. W. Birge. (United States Bureau of Mines, 1949, Technical Paper 726, pp. 1–51).

Problem of Coking Coal in Brazil. F. F. Pereira Pinto. (Mineração e Metalurgia, 1950, vol. 14, Jan.–Feb., pp. 128–129). [In Portuguese]. Brazilian coking coal is produced exclusively in Santa Catarina. The cost of production is so high that it cannot compete with the imported product. The author states that it is necessary to remove 50% of sterile rock to obtain a coal with an ash content of about 38%, and there is little or no mechanization. The coal is transported by a railway working under onerous conditions to a port destitute of port facilities. Finally, the type of shipping used is uneconomical. The coal is mined only for reasons of national interest.

The government will have to back coal utilization research and the possibilities of electro-metallurgical processes must be explored. The Brazilian coal industry needs technical help from the State Mineralogical Department; economic help (creation of mineral development banks to help with credits and relief from taxes) and political help (a guarantee of continuous working without undue government intervention).—R. S.

Increasing Gas Production from Coke Oven Plants. W. C. Wardner. (Proceedings of the American Gas Association, 1948, pp. 291–295). The following methods of increasing the gas output from coke-oven batteries are briefly reviewed: (1) Increasing the firing temperature to reduce the coking time and raising the number of ovens pushed in a given time; (2) varying the rate of light-oil recovery; (3) adding up to 5 gal. (U.S.) of bunker 'C' oil per ton of coal to the charge; (4) making gas by cracking bunker 'C' oil sprayed at 100 lb./sq. in. and 150° F. into two unserviceable ovens with steam; (5) adding small amounts of oil to the coal to control the bulk density; (6) using coke-oven gas mixtures and substitutes for the cool-gas firing; (7) firing with a mixture of natural gas and producer gas; (8) modifying water-gas operation at plants with auxiliary water-gas sets; (9) firing with a mixture of propane and coke-oven gas; and (10) using cannel coal with the coking coal—R. A. R.

REFRACTORY MATERIALS

Good Refractories + Proper Use = Improved Performance. F. A. Czapski. (American Foundryman, 1949, vol. 16, Aug., pp. 54–55). Notes are given on developments in refractories used in malleable iron founding.—J. C. R.

Silica Refractories and Their Use in Open-Hearth Furnaces. F. J. V. de A. Franceschini. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Jan., pp. 207–226). [In Portuguese]. The author examines the specifications for high quality refractories and considers the use of silica bricks for the roofs of open-hearth furnaces from the point of view of stability. Some brief notes are given on Brazilian production of silica refractories.—R. S.

Refractories for Electric Arc Furnaces. J. R. Rait. (British Iron and Steel Research Association: Conference on Foundry Steel Melting, Sept. 22–23, 1949, pp. 27–28). The author shows why silica bricks are used in Britain for the roofs of electric arc furnaces. Andalusite and sillimanite have been tried, but the main objection is their high cost. Side walls are generally of basic brick and the author finds that silica walls increase the fettling charges as compared with basic. The cause of the flaking and spalling of basic bricks in the side walls is that lime and slag, with some magnesia, migrate through the brick until a position is reached equivalent to the freezing point; the flux then freezes and builds up to a maximum, thus creating different zones in the brick, and a crack is invariably found behind the maximum build-up of flux.—R. A. R.

Study of the Behaviour of Chrome-Magnesite Bricks Used for the Roofs of Electric Furnaces. A. T. Kleinberg. (Centre de Documentation Sidérurgique, Circulaire d'Informations Techniques, 1949, vol. 6, Apr.–May, pp. 175–178). This is an abridged translation into French of an article which appeared in Ogneupory, 1949, vol. 14, Feb., pp. 85–90. Data are given from tests on chrome-magnesite bricks taken from different parts of the roof of electric furnaces to determine the causes of heavy erosion.—J. C. R.

Progress Made in the Open-Hearth Plant by the Utilization of Chrome-Magnesite Bricks. H. Barret. (Société Française de Métallurgie, Oct. 4, 1949: Revue de Métallurgie, Mémoires, 1950, vol. 47, Mar., pp. 211–214). A short account is given of the benefits derived from the replacement of silica bricks by chrome-magnesite bricks in the construction of an open-hearth furnace.—A. E. C.

Methods of Analyzing Refractory Consumption. W. A. Greene. (American Institute of Mining and Metallurgical Engineers: Blast Furnace and Steel Plant, 1949, vol. 37, Oct., pp. 1199–1204). Practice at the Fontana Plant of the Kaiser Steel Corporation is described. Roof life in open-hearth furnaces is evaluated in terms of the theoretical 'AISI roof' (American Iron and Steel Institute) of 13½-in. brick, and this criterion is also applied to any patching material employed during a campaign. The life of ports and slope roofs is not assessed by this criterion, but it is found that these parts of the furnace usually last through two campaigns.

Front walls are of especial interest ; patching by replacement of the jambs extends their life considerably and records are kept of this patching. Steel ladle linings are also the subject of much study, and the type and temperature of the heat, the quantity of slag and skull, and the skill in bricklaying are taken into account in assessing the life of a lining.—J. P. S.

Refractories for the Foundry. A. Gunn. (Institute of British Foundrymen : Foundry Trade Journal, 1950, vol. 88, Jan. 26, pp. 87–94). Cupola refractory problems are examined from the point of view of the refractories chemist. The life of a refractory depends on operational factors, but the use of standard shapes instead of special sizes and shapes is advocated. Other factors discussed include types of refractory available, causes of failure in the various cupola zones, slag reactions, compositions, and functions.—J. C. R.

The Evolution of the All-Carbon Blast Furnace. G. D. Elliot. (Blast-Furnace and Coke-Oven Associations of the Eastern States and Chicago District, Oct. 21, 1949). The author gives an account of the development of the use of carbon refractories in the blast-furnaces of the Appleby-Frodingham Steel Company. There are now nine furnaces at Appleby-Frodingham and three at Workington. Since starting to use carbon, these works have installed ten carbon hearths, four carbon boshes, one part-carbon stack, and two all-carbon furnaces.—R. A. R.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Theoretical Considerations in the Operation of Iron Blast Furnaces with Cold Oxygen Carbon-Dioxide Blast. W. Bleloch. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1950, vol. 50, May, pp. 255-292). The systems iron–carbon–oxygen and carbon–oxygen are discussed to assess the feasibility of using cold or regenerated blast consisting of not less than 95 wt.-% of oxygen and CO_2 for the operation of iron blast-furnaces with coke or anthracite. Such blast is referred to as ' carbonated blast ' and its action is based mainly on the reversal of the reaction $C + CO_2 \rightleftharpoons 2CO$ in the stack. This assessment is dealt with at length and it is concluded that the advantages of using cold carbonated blast are : (1) A smaller furnace is needed for a given output of iron. (2) Regenerative stoves are not needed, and blowing equipment is greatly reduced in size. No gas storage is required. (3) The stack column height is reduced and low grade coke, coke breeze, or anthracite may be used as a fuel. (4) Because of the reactivity of the oxygen and the carbon dioxide of the blast with almost any form of carbon, combustibility in air of the coke or anthracite used is not of importance. (5) The saving to be attained, of the order of 50% of the carbon used per ton of pig iron in normal hematite smelting practice, is of crucial importance, not only because of diminished operating costs, but also because of conservation of coking coal reserves, and because anthracite may be used. (6) The reduction of blast volume to roughly one-fifth of the required volume of air blast, and the reduction of the volume of stack gas to less than one half that from an air blast are both of importance, in that much finer burden may be used, with consequent better reduction of ore particles in the stack, and better utilization of coke or anthracite as reducing agent. (7) The reduction in coke consumption will result in a correspondingly lower capital commitment in coke-oven plant per unit of pig-iron production capacity, but this saving, at present price levels, is offset by the capital cost of the required oxygen plant and the carbon dioxide extraction equipment. The use of anthracite avoids the total capital commitment for coke ovens. (8) As compared with high-top-pressure operation with regenerated air blast, operation with carbonated blast shows a higher saving in carbon per ton of pig iron made. (9) The hearth temperature may be easily controlled with carbonated blast by varying the carbon dioxide content of the blast. (10) The use of carbonated blast should be of advantage in the smelting of siliceous, aluminous, and titaniferous ores because of the ease of adjustment of hearth temperature by variation of the carbon dioxide content of the blast.—R. A. R.

Views on Modern Blast-Furnace Technique. J. Szczeniowski. (Métallurgie, 1950, vol. 82, Jan., pp. 25–30 ; Feb., pp. 95–99 ; May, pp. 337-347 ; June, pp. 451–459.) The most frequently used types of blast-furnace stove are discussed from the user's point of view. Some practical difficulties are outlined. No conclusions are drawn regarding the best type of stove. A bibliography of 18 items refers mainly to French and German work. The design and service conditions of burners are described. Modern burners are classed under vertical, internal, and horizontal external types. P.S.S. (Pfoser-Strack-Stum) burners, Hoesch, Dingler, Krupp, Stoecker, and Askania types are described. Heat transfer is discussed and heat-transfer calculations in which the stove is treated as a continuous heat exchanger, are given. Various types of stove brickwork are described.

Finally, methods of insulation are surveyed and the different sorts of valve and the problem of automatic valve control are explained in detail.—R. S.

Reduction of Iron Ores in Electric Furnaces. R. Durrer. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Jan., pp. 20–28). [In Portuguese]. The author discusses the development of electric reduction furnaces, especially the low-shaft furnace, and compares the reactions with those in blast-furnaces. Fuel consumptions of the two types of furnace are compared. Possibilities of future developments are reviewed.—R. S.

A General Method for the Calculation of the Electric Power Costs for Equating the Costs of Pig Iron in the Blast-Furnace and in the Low-Shaft Electric Furnace. T. D. de Souza Santos. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, July, pp. 324–340). [In Portuguese]. In view of the divergency of opinion regarding the limiting costs of electric power for the economic utilization of the low-shaft electric furnace for the reduction of iron ores in comparison with the blast-furnace, the author examines the main economic variables. He determines the cost of electric power for which the costs of production in both cases would be equal. In regions where the cost of electricity is lower than this equivalent, the low-shaft electric furnace would be more economical. Under conditions obtaining in the São Paulo area, the electric furnace would give a lower production cost for pig iron.—R. S.

Five Years of Blast Furnace Operation under Elevated Top Pressure. F. Janecek. (Iron and Steel Engineer, 1950, vol. 27, Jan., pp. 55–62). The author gives particulars of five blast-furnaces in the U.S.A. which have been operating with high top pressure for a considerable time, the first one was driven from May 1944 to May 1945 with the top pressure at 10 lb./sq. in. The constructional alterations necessary are described, and some difficulties encountered and the methods adopted to overcome them are discussed. Nomograms are presented for determining the effect of increased pressure on the blast volume under various conditions of temperature and pressure, and for calculating the ' gas retention time ' in a blast-furnace from the percentage ash in the coke, the furnace volume, the coke rate, and the voids in the ore.

R. A. R.

DIRECT PROCESSES

Relative Reducibility of Some Iron Oxide Materials. E. P. Barrett and C. E. Wood. (United States Bureau of Mines, 1949, Report of Investigations 4569). The investigation reported was undertaken to develop a standard procedure by which the relative reducibility of iron oxide materials could be determined rapidly and accurately in hydrogen, in carbon monoxide, and mixtures of these gases. The descending order of reducibility by hydrogen at 900° C. of six groups of iron oxide materials is (1) limonite, (2) hematite, (3) pellets formed by balling fine moist oxide in a rotating drum at room temperature, followed by heating in a shaft furnace to a temperature below that of incipient fusion, (4) sinter, (5) nodules formed by heating the oxide to incipient fusion in a rotary kiln, and (6) magnetite.—R. A. R.

Comparative Study of the Reducibility of Sinter. H. G. de Carvalho, N. L. Bastos, and E. P. Franca. (Revista de Química Industrial, 1949, vol. 18, Nov. pp. 20–21). [In Portuguese]. The reducibility of sinter produced in the Mineral Production Laboratories (M.P.L.) in Rio de Janeiro was studied by using hydrogen at normal pressure and at different temperatures. Various foreign sinters were compared with the M.P.L. sinter. The method used by the M.P.L. consisted essentially of producing a constant flow of dry hydrogen through 8-mesh sinter in a furnace at constant temperature. The water produced during reduction is measured by the rise in temperature in a calorimeter containing 70% sulphuric acid. The temperature curve was previously calibrated.—R. S.

The Latest Method of Obtaining Pig Iron. The Madaras System. J. B. de Nardo. (Tecnica e Industria, 1949, vol. 27, Dec., pp. 1144–1146). [In Spanish]. The fundamental reactions in six zones of the blast-furnace are described and the neutral rôle of nitrogen is mentioned. Reference is made to the 'hydrogen pulsation' method of Dr. Madaras in the U.S.A. which is being operated on a commercial scale at the Rongurevo plant in Texas.

The principles of the process are: (1) Charging a retort with a mixture of iron ore, coal, and enough water to form a paste; (2) injecting compressed air at 2 to 4·2 kg./sq. cm. pressure and at 815° to 930° C. to burn the coal. In a few minutes the entire mineral charge is heated to 980° to 1095° C. which is the optimum range for hydrogen reduction; (3) injecting hydrogen at a temperature of 815° to 925° C. and at 2 to 8·5 kg./sq. cm. pressure so that it penetrates the entire mass and reacts with the iron oxide to produce steam and metallic iron; and (4) reducing pressure and recuperating the steam and unused hydrogen.

About 50% of the injected hydrogen reacts with the ore to produce sponge iron. Sulphur is oxidized by the hot air and is eliminated by the hydrogen. The Madaras system claims to be six times as economical as the older methods of direct reduction as regards heat economy, and it permits more rapid reduction.—R. S.

A Study of the Comparative Reducibility of some Brazilian Iron Ores. G. Melcher and C. E. V. Cajado. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, July, pp. 341–361). [In Portuguese]. An apparatus is described for measuring the reducibility of iron ores. The rates of reduction by hydrogen of various typical Brazilian iron ores were measured and the influence of factors such as the screen analysis, porosity, and temperature was studied. Data are given for the rates of reduction of canga, itabirite, chapinha, and various hematites compared with typical North American ores. The rate of reduction increases with temperature between 700° and 1000° C. and is lowest at 600° C. This rate is inversely proportional to the volume of the lumps between 3·3 and 15·6 cu. cm., and diminishes rapidly for greater volumes. Generally, the more porous ores are more easily reducible. On the average, Brazilian ores are purer and more compact, and their reducibility is slightly higher than typical North American ores.—R. S.

Direct Reduction of Iron Ore from Charcoal–Ore Mixtures. F. Alvares de Toledo Piza. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, July, pp. 490–497). [In Portuguese]. The results of experiments carried out by the Institute of Technological Research of São Paulo on the direct reduction of Jacutinga ore from the Andrades deposits in Minas Geraes are described. This ore was mixed with charcoal in ceramic or cast-iron crucibles.

A typical analysis of the ore was: 98·6% Fe_2O_3, 69% total iron and 0·03% moisture. Cylindrical briquettes were made 5 cm. in dia. by 8 cm. long of the following mixture: ore 2·0 kg., charcoal 0·6 kg., limestone 0·2 kg., dextrine bond 0·1 kg. Composition of the briquettes was: total iron 68·4%, metallic iron 54·5%, total carbon 0·30%, with apparent specific gravity 1·60, and degree of reduction 79·8%. Other mixtures were tried and it was found possible to produce a suitable sponge iron with a low-temperature process and at low cost. This is of considerable interest in view of the scarcity of scrap and the high price of pig iron.

Cost of Production of Pig Iron in the Tysland-Hole Type Electric Furnace, Using only Charcoal for Reduction. E. L. Fonseca Costa. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, Jan., pp. 16–26). [In Portuguese]. The author examines the costs of producing pig iron for the direct production of centrifugally cast pipes. The calculations are based on data furnished by a firm of electric furnace manufacturers and are adapted to Brazilian conditions in the light of the author's personal experience with an electric reduction furnace of the Brazilian Electro-Metallurgical Co.

In order to benefit by a replacement of the present blast-furnaces by a Tysland-Hole 13,000 kVA. furnace, the price of electric power would have to be decreased by at least 16·7%.—R. S.

Production and Cost of Sponge Iron. E. Tysklind. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, Apr., pp. 180–183). [In Portuguese]. Various reduction processes are reviewed and the economic advantages of the Höganäs and Wiberg processes for the production of sponge iron are emphasized. Costs for the two processes are considered. The advantages of sponge iron over pig iron are summarized and a table is given showing the annual consumption of fuel, labour required, and price of product for the various reduction processes.—R. S.

The Manufacture of Sponge Iron. F. A. de Toledo Piza. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, July, pp. 253–264). [In Portuguese]. The Höganäs and Wiberg processes for the manufacture of sponge iron are described. In spite of its lower heat economy, the Wiberg process may be of greater interest in Brazil. The idea of using sponge iron for making steel is attractive to Brazilian metallurgists in view of the scarcity and high price of scrap.—R. S.

Iron Manufacture without Coke. (Revista de Química Industrial, 1950, vol. 19, Jan., p. 28). [In Portuguese]. The French engineer, Réné Planiol, studied three types of equipment in an attempt to solve the problem of making iron from ore without the use of coke. These consisted of (1) A centrifugal mill to reduce the iron ore to a fine powder; (2) a magnetic separator to 'purify' the iron oxide; and (3) a high-temperature furnace in which the finely crushed ore is 'purified' and reduced to iron in the liquid state in an atmosphere of hydrogen. A pilot plant was installed in Brooklyn by Pluro Inc. (formed in 1946) to perfect the process. Magnetite can be used direct, but hematite must be partially reduced to magnetite in a reducing furnace before it can be separated magnetically. It is hoped that further tests in Texas, where cheap and abundant hydrogen is available, will prove that iron can be made in quantities by this method. No technical details of the process are given.—R. S.

PRODUCTION OF STEEL

A Study of Two Basic Open-Hearth Casts. D. L. Schwartsman and H. J. Ceccantini. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Apr. pp. 211–236). [In Portuguese]. The authors describe the making of a cast of CA 50 steel and of a silicon spring steel. Full logs of heats, details of conditions for oxidation and slag control, variations of composition in bath, slag, and ladle, and basicity-time curves are given.—R. S.

Open-Hearth Steelmaking in Argentina, using National Zapla Pig Iron. B. Podczaski. (Ingenieria e Industria, 1949, vol. 17, Dec., pp. 61–66, 124–128). [In Spanish]. The author describes the most important factors in the production of steel in the Argentine Republic. Fixed basic open-hearth furnaces are the main types used. Raw materials for these are Zapla pig iron and old iron scrap. The Jujuy iron ores produce irons relatively high in phosphorus and silicon (P 0·70–1·20%, Si 0·60–1·20%, S 0·01–0·025%).

The necessity of limiting the amount of slag carried limits the amount of Zapla pig iron which can be used in the charge. The author reviews various suggestions for a solution of the dephosphorizing and desulphurizing problem. Some of these methods merit attention in the Argentine, but require laboratory equipment and suitably qualified personnel. The author confines himself to giving details of the simple method of obtaining the necessary slag composition by controlling the chemical analysis of the charge.

Details of the calculations of the composition of the charge to produce the required slag analysis, of the movement of phosphorus between metal and slag, and of the degree of rephosphorization are given. An example of the working of a heat using 30% of Zapla pig iron in a metallic charge of 20 tons is given.

The author concludes that, in view of the scrap shortage there, pig-iron production should be raised, as Argentinian open-hearth furnaces can transform up to 220 tons of Zapla pig iron per day. The Argentine could then produce carbon tool steels and low-alloy steels which, at present, are being imported.—R. S.

Duplex Process and Its Application in Brazil. R. Wood. (Boletim da Associação, Brasileira de Metais, 1946, vol. 2, Oct., pp. 3–12). [In Portuguese]. The principles of the duplex process for refining pig iron in converters and open-hearth furnaces are reviewed. The principle of the 'electric eye' and its use in controlling the blow is described. There appear to be considerable possibilities for the application of duplexing in Brazil.—R. S.

Basic Electric Steels. F. Fabriani. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Jan., pp. 65–78). [In Portuguese]. The chemical and mechanical properties of specimens

from 250 casts of SAE X-1025 steel are discussed. Practical points regarding oxidation, refining, and control of the silicon during the making of the steel are summarized.—R. S.

The Melting of Basic Electric-Furnace Steel. E. Diepschlag and H. Müller. (Archiv für Metallkunde, 1949, vol. 3, Nov., pp. 369–376). The melting processes for making special steels in basic lined electric furnaces are reviewed with special reference to the use of inferior raw materials and linings as is the case in Germany at the present time.—R. A. R.

Basic Electric Furnace Practice. C. Bradaschia. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, Oct., pp. 63–88). [In Portuguese]. The article is confined to the basic Héroult furnace practice used in the laboratories of the Technological Research Institute of São Paulo. The author does not deal with the principles of the furnace or with the physical chemistry of the process, but refers to the two-slag process of oxidation and reduction. The single-slag process is restricted to cases where selected scrap is available of a composition approximating to the final analysis or where it is necessary only to reduce the carbon content.—R. S.

Production in the Basic Electric Furnace and Properties of Manganese Steels. J. Ramalho. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, July, pp. 293–299). [In Portuguese]. The double slag process is described. Details of moulds, pouring, and heat-treatment are given. Certain defects which can occur in castings of this steel are analysed.

Dephosphorization in the Basic Electric Furnace. C. Bradaschia. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, July, pp. 442–451). [In Portuguese]. The variation of the elements carbon, manganese, silicon, sulphur, and phosphorus is studied during a completely controlled heat in the one-ton basic Héroult furnace of the Institute of Technological Research at São Paulo. It is suggested that the high residual phosphorus content which is often found is due to the absorption of phosphorus by the basic refractory during oxidation and its subsequent reversion to the bath during the reducing phase. The phosphorus content can be reduced at the end of the oxidizing phase. In order to have a minimum P_2O_5 content in the oxidizing slag, the phosphorus in the charge must be as low as possible, or the P_2O_5 in the slag must be diluted.—R. S.

Electric Furnace Melting—Quality Control Creates and Maintains More Uniform Steel and Greater Production. W. O. Igelman and F. S. Nussbaum. (Metal Progress, 1949, vol. 56, Oct., pp. 483, 485). A brief account is given of methods adopted to improve the quality and uniformity of electric furnace steels. The scrap used was more carefully selected and the slag (or the greater portion of it) was removed immediately after the boil to avoid losing high amounts of final alloying additions. Tabular data give particulars of economies effected and improved physical properties.—J. C. R.

Itabira Special Steels Company (ACESITA). (Mineração e Metalurgia, 1949, vol. 14, Nov.–Dec., pp. 8–10). [In Portuguese]. The article contains details of the very interesting and much publicized Companhia Aços Especiais Itabira founded at the end of 1944 for the production of special steels in Brazil.

The undertaking consists of three parts : An iron and steel plant comprising two-phase electric arc furnaces of 20 and 5 tons capacity, one 500-kg. induction furnace, a 10-ton converter and a 300-ton mixer ; one blast-furnace with a 12-ft. hearth ; a rolling mill, forge, and mechanical workshop ; and a hydro-electric station with installed capacity of 28,000 kW.

There is capacity for 55,000 tons a year of finished products, including silicon steel and stainless steel sheets, bars, beams, axles, and automotive parts. The mills include a 24-in. cogging mill, two 3-high and one 2-high finishing mills, and a 14-in. and a 12-in. bar mill, the 14-in. mill consisting of two 3-high and the 12-in. one comprising two 3-high and two 2-high stands for rounds and squares from 2 in. to $\frac{1}{2}$ in. There is also a sheet mill.—R. S.

High-Cr Steel in Acid Arc Furnace. D. C. Hilty. (Journal of Metals, 1949, vol. 1, Sept., pp. 20–23). The chromium–carbon–temperature equilibrium in acid arc-furnace practice has been studied. It was confirmed that the equilibrium relationships previously shown (*see* Journal of Metals, 1949, vol. 1, Feb., p. 91) for basic arc furnaces are also true in acid arc furnaces. One of three trial heats, in which aluminium was fed to the oxidized slag, gave an indication of increase in recovery of chromium from the scrap charged. One heat, purposely melted at higher carbon than usual, gave an indication of possible time saving. Ferrosilicon and lime were ineffective in reducing chromium from the acid slag.—R. E.

High Speed Electro-Hydraulic Arc Furnace Control. A. Garde. (Iron and Steel Engineer, 1949, vol. 26, Nov., pp. 104–108). An illustrated description is presented of a new system of high-speed electro-hydraulic arc furnace control. A note is included on its performance in service.—J. C. R.

Automatic Control of Electrodes in Arc Furnaces. G. R. Bashforth. (Metallurgia, 1950, vol. 41, Jan., pp. 153–154). The principles and practical applications of continuous-type and intermittent-type regulators for automatic adjustment of the electrodes in electric arc furnaces are described.—R. A. R.

Small Steel Mills for Local Markets. H. W. McQuaid. (Iron Age, 1950, vol. 165, Apr. 6, pp. 90–94). To avoid the payment of high freight rates, it is suggested that it is economically possible to construct, near a suitable market, small steel plants of about 100,000 tons/annum capacity. These would operate electric arc furnaces entirely on scrap, and use a continuous mill for the production of bar, wire, rod, sheet, etc. With furnaces of 10–25 tons capacity it is possible to pour killed steel into billet-type moulds, *e.g.*, $2\frac{1}{2}$ in. × 10 in. × 120 in., and thus eliminate the blooming and billet mills ; rimming steel may be poured into ingots of 4 in. × 4 in., and perfect rimming obtained. A further product which might be made in this arrangement is skelp for gas or electric-welded pipe and tube up to 2 in. in dia. : transport costs on pipe are particularly high.—J. P. S.

Studies in the Deoxidation of Iron—Deoxidation by Aluminium. H. A. Sloman and E. L. Evans. (Journal of The Iron and Steel Institute, 1950, vol. 165, May, pp. 81–90). The paper describes the preparation, microscopical examination, and analysis of a series of 19 ingots made by adding quantities of iron oxide and aluminium to 300–500 g. melts of pure iron, *in vacuo*. Results reported include the total oxygen contents obtained by the vacuum-fusion method, aluminium contents, and the chemical and X-ray analyses of the non-metallic residues of alcoholic iodine extraction. The inclusions consist mainly of α-alumina when aluminium is in stoichiometric excess of the oxygen. Where it is not in excess, inclusions also contain hercynite, $FeO.Al_2O_3$, and sometimes magnetite, Fe_3O_4. Where oxygen is in large excess, hercynite occurs mainly as dark idiomorphic particles within the spherical wüstite inclusions. An explanation of the analytical and microscopical evidence is postulated in the light of known phase and equilibrium relationships in the Fe–Al–O system. The difficulty of determining the equilibrium constant of the deoxidation reaction $2Al + 3FeO = 3Fe + Al_2O_3$ is discussed briefly, and in an appendix, by O. Kubaschewski, known data are used to derive a value given by $\log K = -49{,}900/T + 14{\cdot}2 \pm 3{\cdot}0$.

First Report of the Ingot Surface Defects Sub-Committee. (Journal of The Iron and Steel Institute, 1950, vol. 165, May, pp. 41–66). This is a report by the Ingot Surface Defects Sub-Committee of the Ingots Committee of the Steelmaking Division of the British Iron and Steel Research Association. It deals with the occurrence of the principal types of ingot surface defect—cracks, blow-holes, and shelliness—in the three main classes of steel, killed, balanced, and effervescing. In Part I, after defining the types of steel, the various defects are considered separately, attention being directed both to the causes of the defects and to means of control. From this discussion a number of conclusions are drawn, due reference being made to the detailed supporting evidence given in Part II, and it has been possible to make a number of definite recommendations.

The principal factors affecting cracking, apart from the obvious one of the prevention of contraction due to restriction by mould or head, were found to be steel composition, teeming temperatures and speeds, and sulphur contents. The state of oxidation of the metal was known to be the chief factor controlling the formation and distribution of blow-holes ; the effects of some other factors are discussed, but present knowledge is insufficient in the case of balanced steels to control blow-hole depth at all closely.

Shelliness was related chiefly to the control of teeming, especially in the initial stages, and in effervescing steels to conditions in the metal which may allow a sudden fall of the surface level during teeming. The use of mould dressings is discussed.

It is pointed out that works conditions vary so much that conclusions applicable in one instance may not be acceptable in another, and that constant experiment and trial on a wide scale are necessary on certain aspects of the problem before conclusions that are generally acceptable can be reached. A number of lines of future work are proposed. Part II describes the large number of individual works experiments on which the discussion in Part I is based.

Viscosity and Fusibility of Slags. P. Kozakevitch. (Société Française de Métallurgie, Oct. 6, 1949 : Revue de Métallurgie, Mémoires, 1950, vol. 47, Mar., pp. 201–209).

Use of Aluminium in Controlling Grain Growth in Steels. J. Mendes França. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, July, pp. 498–522). [In Portuguese]. All the factors influencing the efficiency of the aluminium addition in the control of grain growth are studied. These include the quantity of the addition, temperature at which the addition is made, rate of the addition in relation to the solidification of the ingot, state of the deoxidation of the bath, etc. An addition of 350 g. to 1 kg. of aluminium per ton of steel is sufficient to obtain fine grain in a 1% carbon tool steel. Methods for determining iron oxide and oxygen in the bath, and the Institute of Technological Research method for determining Al_2O_3 and metallic aluminium, are described. R. S.

FOUNDRY PRACTICE

Basic Principles Common to Foundry Melting Practices. P. C. Rosenthal. (American Foundryman, 1950, vol. 17, Jan., pp. 48–55). Some reactions occurring in the melting of ferrous and non-ferrous metals are explained with particular reference to those promoting the absorption or the expulsion of gases from the melt.—R. A. R.

Foundry Practice in Sweden. R. L. Handley. (Institute of British Foundrymen : Foundry Trade Journal, 1950, vol. 88, Jan. 26, pp. 102–105). Brief details are given of foundry practice at the following Swedish works : A.B. Götaverken, Gothenburg ; Norrahammar Works ; Husqvarna Works ; S.K.F. Works ; and Allmänna Svenska Elektriska Aktiebolaget (A.S.E.A.).—J. C. R.

Applications of the Low-Frequency Electric Induction Furnace for the Melting of Iron. H. A. Werneck. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Jan., pp. 5–19). [In Portuguese]. A study is made of the applications of the low-frequency induction furnace for the production of cast iron, mainly under Brazilian conditions. The principles of the furnace are explained and the advantages over the cupola are stated. A comparison is also drawn with the arc furnace. The use of the furnace under varying conditions of power supply in Brazil is discussed and a description of the cuploa low-frequency duplex process is given.—R. S.

Castings Can Do It Better. B. L. Simpson. (Malleable Founders Society : American Foundryman, 1950, vol. 17, Jan., pp. 34–36). Examples of machinery parts which can be economically produced as castings instead of forgings, or instead of welded components, are described and illustrated. R. A. R.

Cast Iron. A. Guédras. (Métallurgie, 1950, vol. 82, Jan. pp. 33–34, 37). The author discusses spontaneous and induced crystallization. In the cupola, the latter generally obtains and the iron made usually ' inherits ' crystal nuclei from the scrap charged. In order to obtain spontaneous crystallization the iron charged to the cupola must be transformed into a homogeneous solution so that crystalline nuclei would be formed throughout the metal. Two methods of obtaining spontaneous crystallization are superheating, and increasing the solvent (iron). Steel can be added to increase the solvent and to transfer the solid or liquid particles in emulsion to solution. Additions of steel to the cupola combat the phenomenon of ' heredity ' by dissolving the harmful crystalline nuclei. There is, however, a ' steel saturation point ' which, if exceeded, causes piping in the iron. The amount of the steel additions is calculated in relation to the quantity of scrap charged. Average charges consisted of 60% scrap, 30% hematite iron, 10% steel, ferrosilicon, and ferromanganese. Examples of the calculations of steel additions with varying amounts of scrap are given.

The relationships between the physical characteristics of cast iron and the state of the iron carbides, the silicon and carbon contents, and the rate of cooling are discussed.—R. S.

The Use of Babassú Coke in the Cupola. M. Ribeiro Rocha and F. Bocciarelli. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, Oct., pp. 157–164). [In Portuguese]. The Metallurgy Division of the Technological Research Institute studied the behaviour of coke made by the Industrias Babassú Limited works at Kelru in the State of Maranhao. The analysis of this coke was : moisture 7·9% ; volatile matter 3·8% ; ash 5·9% ; fixed carbon 82·4% ; total sulphur trace ; calorific value (dry) 7780 kg.cal./kg. The cupola used had automatic air control, an internal diameter of 45 cm. and a nominal hourly production of one ton. An American coke was used as standard for comparison. Melting practice and slag basicity are fully described. Optimum percentages of coke to metallic charge and of limestone are stated. With Babassú coke, carbon absorption is slightly higher, oxidation of silicion slightly lower, and higher blast pressure must be used than with common coke.—R. S.

Cupola Coke. E. Orosco. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, Oct., pp. 509–544). [In Portuguese]. Correct calculation of the reactivity of coke is important for drawing up heat balances for the cupola. The author's experiments show that a good cupola coke must have as low a reactivity as possible in addition to high mechanical strength and low content of impurities. Generally speaking, cokes with a high distillation temperature should be used for cupolas. The use of highly reactive charcoals for cupola work is considered a possibility provided that it is possible, by chemical and mechanical means, to avoid too rapid a reaction with the oxidizing gases below 600° C. This might also be managed by a change in the design of normal cupolas. R. S.

Production Control in a B.C. Foundry. R. M. Dyke. (Canadian Metals, 1950, vol. 13, Jan., pp. 24–27). Melting practice and production control at the iron foundry of Canadian Sumner Iron Works, Ltd., Vancouver, are described. The iron is inoculated at the cupola spout to produce a refined pearlitic matrix, which is measured by its sorbite constituent ; this iron is called Sorbo-Mat.—R. A. R.

Metal Yield of the Cupola. D. Homem de Milo. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Apr., pp. 173–176). [In Portuguese]. A formula is presented for calculating the quantity of metal melted in a cupola in a unit of time, in relation to the main variables. The use of this formula gave good agreement with practical results.—R. S.

Hot-Blast Cupolas. M. Novinsky. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Apr., pp. 164–172). [In Portuguese]. The recuperation of heat in cupolas is studied from the point of view of coke economy. The possibility of installing the main types of hot-blast cupola in Brazil is considered. A 30% saving in coke consumption is obtained. Higher and more uniform temperature is achieved with low-grade coke. Easier control is possible. Output is increased for a given size of cupola. Sulphur absorption is decreased. Necessary conditions for the installation of recuperation are : (1) A minimum capacity of 5 tons/hr. ; (2) regular casts (at least three times a week) ; and (3) heats of a minimum duration of 3 to 4 hr.—R. S.

Acicular Cast Iron. E. Piwowarsky. (Neue Giesserie, 1950, vol. 37, Jan. 26, pp. 29–31). The production, properties, and applications of acicular cast iron are discussed.—R. A. R.

Nodular Cast Iron—A New Material. W. Patterson. (Werkstatt und Betrieb, 1950, vol. 83, Jan., pp. 18–20). The production, microstructure, and properties of nodular cast iron are reviewed and its sphere of application is discussed. R. A. R.

Factors Affecting Development of Ductile Iron. D. J. Reese. (Gray Iron Founders' Society : Foundry, 1950, vol. 78, Jan., pp. 58–62, 216, 217). The influence of manganese, silicon, carbon, and phosphorus on the properties of ductile cast iron made with magnesium is discussed. If a ferritic ductile iron with high shock resistance is required, the manganese should be about 0·25%. The phosphorus should be kept as low as possible. Carbon provides a means of controlling the castability, feeding, and shrinkage characteristics. R. A. R.

Problems in Producing Ductile Iron. M. Kuniansky. (Foundry, 1950, vol. 78, Jan., pp. 62–64). Some of the results obtained in the manufacture of ductile cast iron by the Lynchberg Foundry Co., are reported. Test data are presented on 8-in. cast-iron pipes 18 ft. long, cast by the Super-de-Lavaud method using irons treated with nickel–magnesium, nickel–silicon–magnesium, and magnesium without nickel,

all inoculated with ferrosilicon. High recoveries of magnesium were obtained after allowing for that used by the sulphur. A good annealed low-phosphorus ductile iron pipe had a tensile strength in the wall of 75,000 lb./sq. in., a bursting tensile strength of 52,000–62,000 lb./sq. in., a modulus of rupture in the ring-crushing test of 125,000 lb./sq. in., an elongation of 5% min., and a resistance to impact of 30 blows of a 50-lb. hammer dropped from 5 ft. without failure. R. A. R.

Inoculation of Cast Iron. F. Bocciarelli. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, Oct., pp. 165–188). [In Portuguese]. The effect of graphitizing inoculation on the mechanical properties of cupola cast iron is studied. Inoculation processes most practical and available to foundries and the compositions and types of inoculation most advisable for given cases are discussed. For maximum effect the amount of inoculant added was 0·4–0·5%. The teeming temperature must be as low as possible.—R. S.

Development of Furnaces for Malleable Iron Annealing. C. H. Martin and H. J. Hammond. (Foundry, 1950, vol. 78, Jan., pp. 80–83, 209–213). Improvements in the design of annealing furnaces for malleable iron castings are described with particular reference to furnaces installed by the International Harvester Company. Reduced annealing times and fuel economy have been made possible by using light-weight refractory linings, reducing dead weight by loading castings on heat-resisting alloy trays, making the furnaces gas-tight, and heating with radiant tubes.—R. A. R.

A Study on the Malleablization of Cast Iron. T. Kitice. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, July, pp. 389–399). [In Portuguese]. Some of the factors affecting the number and size of the graphite nodules during malleablization are discussed. These include chemical composition, rate of heating, and variation of section. Carbon and silicon have an almost identical effect. Rapid heating increases the size of nodules and decreases their number. Greater internal stress produces rounder nodules.—R. S.

Manufacturing Cycle for Steel Castings. M. A. Moraes. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, Apr., pp. 185–210). [In Portuguese]. The author deals mainly with moulding processes, drawing attention to points in design, core-making, systems of feeding, and types of pouring heads. The problems of progressive and directional solidification are reviewed, and the idea of ' orientating ' the solidification to produce sound castings is discussed. The use of chills is explained.—R. S.

Compositions and Properties of Foundry Sands Studied at the I.P.T. [Technological Research Institute] at São Paulo. R. Refinetti. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, July, pp. 75–94). [In Portuguese]. The essential characteristics (size, form, and distribution of particles, percentage of bonding material, refractoriness, and expansion) are considered and conveniently summarized in tables. The question of fuel is discussed. Core sand mixtures and binders are described and the results of tests on foundry sands for cast iron, steel, bronzes, brasses, and aluminium are summarized.—R. S.

Fundamental Ideas on Moulding Sands, and Comparative Study of Types of Natural and Synthetic Sands. C. Dias Brosch. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, July, pp. 51–58). [In Portuguese]. The author defines moulding sand and stresses the importance of clearly specifying compositions and service conditions. A classification is suggested based on : (*a*) Origin (natural, semi-synthetic, and synthetic) ; (*b*) condition (new or used) ; (*c*) position in mould to which sand will be applied ; (*d*) moisture ; (*e*) type of metal to be cast ; and (*f*) size and thickness of castings. A useful table summarizes technical and economic advantages and disadvantages of natural and synthetic sands.—R. S.

Steel Foundry Sands. C. Dias Brosch and R. Mottin. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Oct., pp. 451–464). [In Portuguese]. The addition of an oxidizer (MnO_2) to moulding sand with the use of flux on the mould surface are aids to good finish on the casting. Phenomena related to surface finish are considered and the tests carried out to avoid metal penetration are described.—R. S.

A Study of the Workable Green Strength of Core Mixtures. (Transactions of the American Foundrymen's Society, 1949, vol. 57, pp. 386–391). This report (by the A.F.S. Subcommittee on Core Strength) describes methods of testing core mixtures in the green state so as to establish the ability to make a standing core, to carry an overhang section, to resist cracking on rolling-out or handling, and to resist sagging on handling.—R. A. R.

Powdered Charcoal as an Addition to Moulding Sand. T. Kitice. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Jan., pp. 94–98). [In Portuguese]. Powdered charcoal was added to synthetic moulding sand with a view to reducing costs. Apiaí charcoal was compared with lignite and Cardiff coal. Sea sand was used as a base. Apiaí charcoal resisted metal penetration to a greater degree than the other two forms of carbon. There probably is an optimum screen analysis and volatile matter content for the best finish of casting. This charcoal gave good finish to the castings.—R. S.

Inspection of Foundry Sands. C. Dias Brosch, Dino Ferraresi and H. Corrêa Goncalves. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, July, pp. 362–374). [In Portuguese]. Humidity and size-grading are the two most important factors in the routine inspection of foundry sands. Size-grading refers to the portion of the material which will pass through a 150 Tyler mesh or a National Bureau of Standards No. 140 mesh. The factors affecting optimum humidity and size are discussed.—R. S.

Flasks and Rigging for Steel Castings. J. H. Hall. (Foundry, 1950, vol. 78, Jan., pp. 71–73, 205–208 ; Feb., pp. 98, 99, 135–138). Various types of flask, jacket, and bottom board for moulding for steel castings are described and illustrated in Part I, and the calculation of the lifting force of molten metal on the cope and cores is explained in Part II.—R. A. R.

Repetition Patternmaking. K. L. Futter. (Proceedings of the Institute of British Foundrymen, 1949, vol. 42, pp. B125–B131). Recommendations are made on the production of metal patterns, with special reference to aluminium patterns the advantages of which are pointed out.—R. A. R.

Information Needed to Produce Satisfactory Pattern Equipment. R. G. Christensen. (Transactions of the American Foundrymen's Society, 1949, vol. 57, pp. 456–458). The author outlines the information required to produce satisfactory patterns ; he believes that the foundry which is to use the pattern, not the pattern-maker, should have the responsibility of specifying and designing the pattern equipment.—R. A. R.

Control Casting Distortion. A. E. Wells. (American Foundryman, 1949, vol. 16, Dec., pp. 48–49). The effect of metal shrinkage and means of allowing for distortion when making patterns are studied by classifying castings according to their general shape. The distortion to be expected with castings of **U, V, L, C,** and segment shapes is explained. R. A. R.

Gating Controls Temperature Gradients in Steel Casting. J. A. Shuffstall. (American Foundryman, 1949, vol. 16, Aug., pp. 52–53). An illustrated description of the method of producing large steel cylinders (weighing 45,000 lb.) for big hydraulic presses is presented.—J. C. R.

Types and Examples of Feeders for Castings. M. A. Moraes and F. Bocciarelli. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, June, pp. 33–50). [In Portuguese]. The authors attempt to standardize the nomenclature for feeders. Seventeen drawings of common types of feeder are given. The classification is based on the position of the pouring head in relation to the mould.—R. S.

A Study of the Dimensioning of Pouring Heads for Castings. C. Dias Brosch and O. Longo. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, Jan., pp. 41–56). [In Portuguese]. A general method of calculating the size of gates for castings is given. The flow of metal into a mould possesses its own kinetic energy due to two types of force acting simultaneously : (*a*) The force exerted by the metal in the mould ; (*b*) the force transmitted by the static pressure of the column of metal in the pouring head. ' Shock areas ' are first estimated and then, by empirical relations, the remaining dimensions of the gates are determined. The ' shock areas ' for different metals are compared, and the dimensional relationship between them and the other feeder sections is considered. An example of the application of these calculations to a 40-kg. bronze casting is described.—R. S.

Triple-Groove Sheave Casting Presents Rigging Problems. N. A. Birch. (American Foundryman, 1950, vol. 17, Jan., pp. 25–30). The Gating and Risering Committee of the American Foundrymen's Society sent out drawings of a 9-in. triple-groove belt wheel to 450 foundries. The casting

was intended to introduce difficult gating and risering problems and the foundries were invited to submit proposals as to its production. Sixty-two replies were received, and these are analysed in this paper.—R. A. R.

How to Select Proper Squeeze Piston Size in Molding Machines. W. W. Eichenberger. (American Foundryman, 1950. vol. 17, Jan., pp. 56–57). In calculating the size of the squeeze piston for a moulding machine the following variables must be considered : (1) Area of flask ; (2) air pressure available at the machine ; (3) sand pressure required to give sufficient mould hardness ; and (4) the metal to be cast. A convenient nomograph for the rapid determination of the diameter of the squeeze piston is presented.—R. A. R.

Developing Standard Data Tables for a Four-Man Molding Unit. M. T. Sell. (Transactions of the American Foundrymen's Society, 1949, vol. 57, pp. 287–306). The paper presents the fundamentals necessary for making time-motion studies of the operation of a four-man moulding unit. The various elements of the operation are defined and charted, and standard data tables are developed.—R. A. R.

The Core-Blowing Machine. J. Hagen. (Neue Giesserei, 1950, vol. 37, Jan. 1, pp. 2–8). The theory and practice of core-blowing are discussed and many types of core-blowing machine are described and illustrated.—R. A. R.

Core Handling Simplified in Modernized Foundry. (Foundry, 1950, vol. 78, Jan., pp. 138–140). The core-baking facilities at the foundry of the Oliver Corp., Charles City, Iowa, are described. There are two convection-heated conveyor-type ovens. Each oven has two heating zones and a long cooling chamber. There is a hydraulic core loader and unloader for transferring the cores to and from the conveyor racks.—R. A. R.

Foundry Core and Mould Drying. M. Guédras. (Métallurgie, 1949, vol. 81, Oct., pp. 29, 31, 33). A short account of core and mould drying practice and the ovens used for this purpose, is presented.—J. C. R.

Infra-Red Drying and Heating of Foundry Cores. M. Déribéré. (Métallurgie, 1949, vol. 81, Nov., pp. 21, 23, 25). An illustrated description is presented of a stove using infra-red heating for drying and baking cores, which is in use at the Saint Pierre-des-Corps works of the French National Railways. Details are given of tests carried out with this stove to determine its efficiency in drying and heating cores, with data on the power consumed and period of heating.—J. C. R.

Principles of Founding Gray Cast Iron for Piston Rings. O. Madono. (Bulletin of the Institute of Physical and Chemical Research, vol. 20, No. 10, pp. 823–837). [In Japanese].

Designing Cast Iron Crankshafts and Centerframes for Diesel Engines. T. O. Kuivinen. (American Foundryman, 1949, vol. 16, Aug., pp. 28–32). An investigation is reported to determine if, by careful design, cast construction could be used for medium-weight diesel engines instead of welded steel fabricated framework. A brittle lacquer known as 'Stresscoat' was used to indicate the most highly strained regions and as a result the shape of the parts could be redesigned. Strain gauges were also used to record strain values at various locations on the framework of the engine, particularly where atmospheric conditions were too variable to depend on consistency when using Stresscoat. The author is satisfied with the possibility of using cast construction for diesel engines.—J. C. R.

Modern Practice in Investment Casting. H. Brown. (Foundry, 1949, vol. 77, Nov., pp. 82, 83, 205–212 ; Dec., pp. 93, 241–248 ; 1950, vol. 78, Jan., pp. 74–78, 182). A comprehensive account of investment casting is given. Part I presents data on the expansion of waxes, silica, and mixtures containing silica, and discusses the properties of pattern and investment materials. Part II describes the preparation of the mould, gating and pouring practice, and the application of compressed air and other means of applying pressure. Part III deals with the structures obtained and the effects of gating practice, and mould and metal temperatures on the properties of cast aluminium and copper-base alloy test bars.—R. A. R.

Precision Investment Casting. A. W. Merrick. (Metal Progress, 1949, vol. 56, July, pp. 53–57). Various aspects of the precision investment casting process are discussed, reference being made to melting and casting methods, mechanical properties of casting, consistency of the properties, and some of the applications to which investment casting is particularly suited.—J. C. R.

Centrifugal and Vacuum Investment Casting. E. F. Ross. (Steel, 1949, vol. 125, Nov. 7, pp. 116–117, 144). Practice in investment casting carried out by Electronicast Inc., Chicago, is described. Some wax patterns are used, but in general a polystyrene plastic is employed. The patterns are dipped first in a silica slurry and when this is dry, a box is placed over the coated pattern and filled with the secondary investment. The moulds are then dried in an electric oven and 'burned out' in a gas-fired oven. Moulds are filled with metal, melted by induction heating, either by centrifugal methods or by a process in which the metal is drawn in by vacuum.—J. P. S.

Precision Casting Provides Low-Cost Production of Small Intricate Parts. A. H. Allen. (Steel, 1949, vol. 125, Dec. 26, pp. 50–52, 67). The Michigan Steel Casting Co., Detroit, uses the precision ('lost wax') casting method for a variety of small articles in stainless steel and other materials. Wax patterns are used ; the primary investment in which the patterns are dipped consists of colloidal silica, silica flour, iron oxide wetting agents, accelerators, and water. The secondary investment is a coarser mixture of silica, calcined clay, and liquid binder ; a vibrating table assists settlement as it is poured into the flasks. The investment gels in about 90 min. and is then dried : at this stage the wax melts out and is reclaimed. The moulds are then preheated to 1600–1850° F. (870–1010° C.) before pouring. The metal is heated in induction furnaces and air pressure assists mould filling. After cooling and shake out, the investment is reclaimed, a specified proportion of new materials being added.—J. P. S.

U.S. Navy Casting Research. H. H. Harris and E. F. Ross. (Foundry, 1949, vol. 77, Nov., pp. 80, 81, 166–172 ; Dec., pp. 86–90, 116, 118). An investigation of the centrifugal casting of steam turbine rotor discs and blades in one piece using a nickel–chromium–cobalt alloy (21–23% of each element) and a 38/18 nickel–chromium steel is reported.

Casting of Steel. F. Fabriani. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Apr., pp. 297–302). [In Portuguese]. The casting of rolling-mill housings for a São Paulo firm is described. A feeder head corresponding to 20% of the effective weight of metal is used in casting a big-end-up ingot with height of ingot three times the mean diameter. The corresponding conditions of feeding and the directional solidification of a flat elliptical section widening towards the top are discussed.—R. S.

Notes on Large Ingot Moulds. M. A. Moraes. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Jan., pp. 185–206). [In Portuguese]. A general survey of the manufacture of large ingot moulds is made. The different processes of moulding and the compositions used are stated. A study of dimensions, shapes, and chemical characteristics furnishes data which explain the losses in moulds. The phenomenon of growth in irons subject to severe temperature conditions is considered. The effect of silicon and other elements on the graphite structure is summarized.—R. S.

Car Engine Piston Rings Centrifugally Cast as Sleeves. P. Januszewicz. (Prace Badawcze Glownego Instytutu Metalurgii i Odlewnictwa, 1949, vol. 1, pp. 195–201). [In Polish]. Centrifugal casting trials for piston rings for motor-car engines have been carried out. The application of a lining of dry silica sand 10 mm. thick gave better results with regard to the shape, size, and distribution of graphite flakes than the use of a mould preheated to 600° C. before casting.

Modern Applications of Centrifugal Casting in the Motor Industry. T. E. Twigger. (Tecnica e Industria, 1950, vol. 28, Jan., pp. 49–54). [In Spanish]. The author discusses the advantages of centrifugal casting for the production of tubes, cylinder liners, sleeves, and valve seats, and describes various types of mould and centrifugal casting machine.—R. S.

Cast Permanent Magnets. A Braybrook and D. Hadfield. (Institute of British Foundrymen : Foundry Trade Journal, 1950, vol. 88, Jan. 26, pp. 95–101). An illustrated account is presented of cast permanent magnets, their development, moulding, melting, pouring, and magnetization.—J. C. R.

Some Aspects of the Problem of Equipping a Metallurgical Industry. M. Siegel. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, Oct., pp. 47–62). [In Portuguese]. The present work attempts to focus the various aspects which have to be considered when equipping a metallurgical industry.

A detailed discussion of the factors affecting the equipping of a mechanized foundry industry includes such items as

wages, depreciation, and maintenance. Much of the data is based on North American statistics, but the study is a timely one for Brazilian industry in view of the possibilities immediately after the war of importing the best foreign technical equipment.—R. S.

A Modern British Iron Foundry. (Iron and Coal Trades Review, 1950, vol. 160, Jan. 20, pp. 145–148). *See* "New Mechanized Foundry of Ruston and Hornsby, Ltd." Journ. I. and S.I., 1950, vol. 165, May, p. 112.

Southern Foundry is Designed for Mass Production. E. Bremer. (Foundry, 1949, vol. 77, Dec., pp. 68–71, 249–251). A description, with numerous illustrations, is given of the foundry of Jackson Industries Inc., Birmingham, Ala. Castings for the motor-car, agricultural, and house-fitting industries are made at the rate of 15 to 18 tons/hr., the iron being supplied from one of two 68-in. cupolas. Moulding is performed at machines beside two continuous car-type conveyors. The moulds move continuously from the moulding stations to the pouring floors. Full ladles suspended from an overhead monorail travel along escalators synchronized with the mould conveyors, these escalator pouring floors facilitate pouring, speed up the procedure, and reduce wastage of hot metal. About 650 lb. or 8500 cu. ft./min. of air is used to melt 15 to 18 tons of iron per hour. The iron at the spout is at a temperature of 2700° to 2800° F.—R. A. B.

The Foundry Industry in Argentina. Macedonio Z. Lopez. (American Foundryman, 1949, vol. 16, Dec., pp. 34–38). An account is given of the present stage in the development of foundries in Argentina. Increased mechanization is desirable but is hindered for many reasons, chiefly because of a scarcity of supervisors and foremen capable of handling mechanical equipment, and the reluctance of management to invest heavily in new equipment.—R. A. B.

Mechanized Foundry Makes Farm Implement Castings. P. Dwyer. (Foundry, 1950, vol. 78, Jan., pp. 66–69, 152, 154). A brief illustrated description is given of the grey iron foundry of the Ohio Cultivator Division, National Farm Machinery Co-operative Inc., Bellevue, Ohio. Metal is supplied by two 42-in. dia. cupolas operating on alternate days. A battery of 30 moulding machines in two lines of 15 is served by two conveyor units 248 ft. long. Pouring takes place at the end loops of the conveyors from 250-lb. ladles suspended from a monorial and operated by one man with a small hoist and a side lever.—R. A. B.

Possibilities of Mechanization of National [Brazilian] Foundries. M. A. Moraes. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Apr., pp. 319–332). [In Portuguese]. Based on observations in North American foundries, the author studies the possibilities of mechanizing Brazilian foundries. He concludes that mechanization is possible for certain production lines in Brazil, such as sanitary materials, electric motor frames, railway castings, parts for textile machinery, elevators, and dental instruments. The following provisions would be necessary for the adaptation of Brazil's foundries: (1) Continuity of flow of raw materials; (2) facilities for series casting adapted to mixed orders; and (3) inspection for uniformity and reduction of rejections.—R. S.

Mechanization and Modernization of Foundries. E. J. Ash (Ingenieria e Industria, 1950, vol. 18, Jan.–Feb., pp. 91–95). [In Spanish]. The author considers to what degree it is economical to mechanize foundries in the Argentine, in view of the great demand for castings and the shortage of labour. A brief motion study is made of the movement of raw materials and moulds, and time-study tables are given relating to the preparation of various types of mould. The production of castings is limited by the quantity of moulds produced in an 8-hour day. Electric power is 150 times more economical than manual labour. Manual labour must be used only where it is difficult to replace human skill.—R. S.

Mechanization in Iron Foundries. F. D. Homem de Milo. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, Oct., pp. 89–102). [In Portuguese]. The mechanization of foundries has two main objects: increase in output and in hygiene. The principle items connected with foundry mechanization, including moulding machines for squeezing, jolting, stripping and roll-over operations, sand treatment, and pattern making, are surveyed.—R. S.

Quality Control in Steel Foundries. J. Přibyl. (Hutnické Listy, 1950, vol. 5, Jan., pp. 17–20; Feb., pp. 66–69). [In Czech]. The author deals with the technical and administrative aspects of quality control in steel foundries, discussing successively the checking of raw materials, patterns, moulds, the melting process, cleaning, and inspection. The need is stressed for (*a*) preventing the mixing of high-alloy and low-alloy scrap, (*b*) correct drying of the wood for patterns, (*c*) testing varnishes for patterns, (*d*) testing sand, (*e*) testing the sand from each truck load, (*f*) checking the drawings and demanding changes of design if necessary, and (*g*) checking patterns and moulds after the first casting. When non-destructive testing apparatus is not available, the presence of trapped gas can be ascertained by drilling holes which are afterwards welded up.—E. G.

Causes of Rat-Tail Casting Defects. (Final Report of A.F.S. Committee on Physical Properties of Iron Foundry Moulding Materials at Elevated Temperatures: Transactions of the American Foundrymen's Society, 1949, vol. 57, pp. 526–534). A progress report on this work has already appeared (*see* Journ. I. and S.I., 1949, vol. 161, Jan., p. 62). The conclusions reached include: (1) When both hot compressive strength and confined expansion are high the sand properties are conducive to rat-tail formation; (2) the best laboratory tests to establish whether a sand is likely to produce this defect are the hot compressive strength at 1100° F. and confined expansion at 1500° F.; (3) additions to sands which lower the hot compressive strength give good results in reducing rat tails; (4) increasing the coarseness of the sand is helpful; (5) the use of cushioning materials such as wood flour, cereal, or bran, is a means of reducing or eliminating rat tails; and (6) a high moisture content is not a direct cause, but may be an indirect cause of this defect.

R. A. B.

Fluidity of Metals. J. E. Worthington. (Iron and Steel, 1949, vol. 22, Dec., pp. 615–619; 1950, vol. 23, Jan., pp. 9–11). Factors affecting the fluidity of metals, many types of fluidity tests, and the results obtained, as reported in the literature to which there are 29 references, are reviewed.

R. A.B.

The Solidification of Metals. E. Scheuer. (Proceedings of the Institute of British Foundrymen, 1949, vol. 42, pp. B103–B111). The theory and mechanism of the solidification of metals and alloys are explained and general recommendations on the reduction of shrinkage cavities are made.—R. A. B.

Modernized Cleaning Room Handles Wide Range of Castings. R. H. Herrmann. (Foundry, 1949, vol. 77, Dec., pp. 82–85, 218–222). A description is given of the equipment and methods for cleaning castings, with special reference to the Hydro-Blast unit, at the foundry of Fairbanks, Morse and Co., Beloit, Wis. The Hydro-Blast room is 20 ft. wide, 40 ft. long, and 18 ft. high with no roof; it has swing doors at each end and one side, and at each end are two 12 ft. dia. turntable platforms on which are placed the castings to be cleaned. On the closed wall there are three elevators each with a sliding carriage holding the water and sand ejection nozzle. These carriages have a vertical movement of 11 ft. The water supply at 1800–2000 lb./sq. in., the nozzle movements and the turntables are controlled from behind windows in the upper part of the wall.—R. A. B.

How to Measure Surface Roughness of Castings. G. Hobman. (American Foundryman, 1949, vol. 16, Oct., pp. 46–47). The surface-roughness meter described consists of a tripod support with leg contact points machined flat $\frac{1}{16}$ in. in dia. with a rotatable disc carrying a phonograph needle offset from centre so that it traverses a circumference of $\frac{1}{2}$ in. in one revolution of the disc. Vertical movements of the needle are indicated on a dial reading in 0·0005 or 0·0001 in. divisions. The disc has 50 graduations round the edge. The instrument is held in contact with the casting while the disc and needle are lifted, rotated, and lowered in successive positions; the dial gauge readings are noted and a graphical representation of the surface traversed can be made.—R. A. B.

Approach to Standard Costs in the Foundry. F. Ruffolo. (Transactions of the American Foundrymen's Society, 1949, vol. 57, pp. 415–432). A costing system for arriving at standard costs in a foundry is explained.—R. A. B.

Cleaning up the Foundry Can Pay Dividends. B. Melnitsky. (Foundry, 1949, vol. 77, Nov., pp. 84–87, 186–190). The importance of maintaining good lighting and clean conditions in foundries is emphasized, and recommendations regarding this are made.—R. A. B.

Industrial Hygiene in the Foundry. H. J. Weber. (Transactions of the American Foundrymen's Society, 1949, vol. 57, pp. 567–575). Silicosis, lead poisoning, and other occupational diseases in the foundry are discussed, and certain measures such as improved lighting, local dust exhausting systems, and the use of water containing a wetting agent to soak cores before removal and to moisten floors before sweeping, are advocated.—R. A. R.

Planned Foundry Dust Control. T. F. Hatch. (Gray Iron Founders' Society: American Foundryman, 1949, vol. 16, Nov., pp. 33–35). The importance of adequate dust control in foundries is emphasized. Some types of equipment are illustrated and briefly described.—R. A. R.

Do You Consider the Protection of Your Foundrymen? H. Bönig. (Neue Giesserei, 1950, vol. 37, Jan. 26, pp. 25–29). Measures for preserving the health and preventing accidents to men in the foundry are considered.—R. A. R.

Basic Equipment for Foundry Chemical Laboratories. (American Foundryman, 1950, vol. 17, Jan., pp. 40–42). The Cupola Research Committee of the American Foundrymen's Society make recommendations on planning a chemical laboratory and present a list of the equipment necessary for the close control of foundry processes.—R. A. R.

HEATING FURNACES AND SOAKING PITS

Extension Plans for Koninklijke Nederlandsche Hoogovens en Staalfabrieken N.V., Ijmuiden. (Metalen, 1950, vol. 4, Jan., pp. 88–94). [In Dutch]. A summary is given of the extensions which are in view at the works of the above Dutch company. They include soaking pits to take 15-ton ingots, a continuous hot wide-strip mill, a cold temper mill, and a tinning plant, with all the necessary auxiliary machinery.—R. A. R.

New Soaking Pit Installation Controls Ingot Temperatures within Plus or Minus 10° F. D. Reebel. (Steel, 1949, vol. 125, Nov. 21, pp. 90, 91). A brief description is given of eight new soaking pits designed by the Salem Engineering Co., for the Allegheny Ludlum Steel Corp., Brackenridge, Pa. The pits, which are 13 ft. in dia. and 7 ft. high, are tangentially fired with either natural gas or oil. Automatic temperature and fuel/air ratio controls are provided as well as meters to record and integrate the gas flow.—R. A. R.

Forging Flexibility Enhanced by Gas Fired Furnace. J. R. Ross. (Steel, 1950, vol. 126, Jan. 16, pp. 61–62). A walking-beam furnace has been installed at the Chevrolet Forge Division of General Motors Corp., Detroit, for heat-treating billets for forging; its capacity is 2200 lb./hr. of bars up to 1½ in. round, square, or flat, and up to 30 in. in length. The bars are heated up to 2250° F. (1230° C.) for forging.—J. P. S.

Induction Furnaces. O. E. Setubal. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Jan., pp. 142–156). [In Portuguese]. A classification of induction furnaces is given. The study covers coreless induction furnaces, regulation of voltage, potential for high-frequency furnaces, losses, and refractories.—R. S.

Induction Furnaces and Their Applications in Industrial Metallurgy. P. G. Paula Leite. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Jan., pp. 157–174). [In Portuguese]. After describing the theoretical principles of coreless induction high-frequency furnaces, the author discusses details of the furnaces proper and of the power supply. Interesting points in the operation of these furnaces are stated and some notes on operational costs are given. R. S.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Commercial Heat-Treatments. V. Chiaverini. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Jan., pp. 117–142). [In Portuguese]. The author describes the various heat-treatment processes and their applications and refers to common items of equipment. A useful description is given of the Heat-Treating Section of the Institute of Technological Research (I.P.T.) at São Paulo.—R. S.

Common Methods of Hardening Steel. J. Mendes França. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, July, pp. 59–74). [In Portuguese]. The relative value, efficiency, and difficulties of methods of hardening (excluding salt and lead baths) are discussed.—R. S.

The Heating and Cooling Power of Liquid Medium Bath. S. Sakui and K. Sato. (Journal of the Scientific Research Institute, 1950, vol. 44, Jan., pp. 102–113). The changes in the electrical resistance of metal wires heated and cooled to different temperatures in water, oil, and molten salts were measured using an electromagnetic oscillograph, and from this the heating and cooling rates were calculated.—R. A. R.

Good Hardening. K. Bielau. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1950, vol. 5, Jan. 31, pp. 6–8). Recommendations for the achievement of good results in the hardening process are made. These include avoiding abrupt changes of section, providing additional thickness in the raw material to allow for removal of the decarburized surface, and providing adequate means of controlling the heating process.—R. A. R.

Induction Surface Hardening. H. Bühler. (Werkstatt und Betrieb, 1950, vol. 83, Jan., p. 26). German developments in induction hardening in the period 1939–1946 are reviewed. R. A. R.

Scale Reduction in Controlled Atmosphere Cycle Annealing. C. A. Payntor. (Industrial Heating, 1950, vol. 17, Jan., pp. 42–49, 169–170). A description is given of an annealing furnace for the continuous heat-treatment of forged rear axles for motor cars at the works of Dana Corp., Fort Wayne, Ind. The furnace is fired with natural gas burning in **U**-tubes and the protective atmosphere (approximate composition: H_2 21%, CO 12%, CO_2 5%, CH_4 0·4%, balance N_2) reduces the scale so that the forgings are easily machined.—R. A. R.

Mass Production of "Raydex" Hardened Plow Shares. (Industrial Heating, 1950, vol. 17, Jan., pp. 26–38, 182). The processes by which the Oliver Corporation, South Bend, Indiana, make plough shares from rolled blanks of 0·95% carbon steel are described. After passing through the gas-fired hardening furnace which has an automatic blade removal mechanism, two holes are punched in it and one end is trimmed. The next operation is quenching in a 'merry-go-round' quenching machine which is done in oil at 120° F. and produces a hardness of 444 to 534 Brinell. This is followed by tempering, the fitting of bolts, grinding, polishing, and, finally, dipping in a solution to prevent corrosion.—R. A. R.

The Production of Steel Sheets, in Particular for Enamelling. E. Schauff. (Metalloberfläche, 1950, vol. 4, Jan., pp. A10–A13). In this review of the processes of making steel sheets, which includes the annealing, it is shown that considerable progress has been made in recent years, and that a great many factors contribute to the quality of the product.—R. A. R.

Surface Hardening by the Gaseous-Fuel/Oxygen Flame. H. Bühler. (Werkstatt und Betrieb, 1950, vol. 83, Jan., pp. 24–25). Developments in the flame-hardening process in Germany in the period 1939–1946 are reviewed.—R. A. R.

Electric Furnaces in the Hardening Shop. R. Hamacher. (Werkstatt und Betrieb, 1950, vol. 83, Jan., pp. 14–15). Some modern electric furnaces for the heat-treatment of tools are described and recommendations on the selection of a furnace for high-speed steel are made.—R. A. R.

FORGING, STAMPING, DRAWING, AND PRESSING

Planned Machinery Maintenance in the Heavy Forging Shop. H. Gummert and W. Bücking. (Stahl und Eisen, 1950, vol. 70, Mar. 30, pp. 279–284). The cost of maintenance in relation to the capital cost of the machinery and equipment in a heavy forging shop is considered and the following matters relating to maintenance are discussed: (1) Planning maintenance with the least disturbance to production; (2) training of maintenance men; (3) observing and investigating indications of damage; (4) major overhauls; (5) avoidance of unnecessary repairs; (6) prevention of overloads; and (7) stocking spare parts.—R. A. R.

Supervision of Operations in Large Forging Shops. H. Gummert. (Stahl und Eisen, 1950, vol. 70, Mar. 30, pp. 275–279). The allocation of responsibility and the organization of supervision, control, and costs in heavy forging shops are discussed.—R. A. R.

The Preheating of Compressed Air in the Forging Shop. O. Günthner. (Stahl und Eisen, 1950, vol. 70, Mar. 30, pp. 271–275). The economic advantages of preheating the air for pneumatic forging presses are pointed out. The danger of explosion has been practically eliminated by installing oil removers or by using turbo-compressors. The air is now

usually preheated to 160–200° C. It is more advantageous to place the recuperator between the air receiver and the press than between the compressor and the receiver. The pros and cons of having a recuperator for each press or a single large recuperator for all the presses are considered, and some different designs of recuperator are briefly described. R. A. R.

Compressed Air Service in Forge Shops. E. Pampus. (Stahl und Eisen, 1950, vol. 70, Mar. 30, pp. 268–270). The use of compressed air for forging hammers is discussed. Data on consumption in different forge shops are given and recommendations on the selection of compressors and pressure are made with notes on the advantages of preheating the air. It is shown to have many advantages over steam, except where surplus steam is available at low cost.—R. A. R.

The Development of Press Forging Machinery. E. Müller. (Stahl und Eisen, 1950, vol. 70, Mar. 30, pp. 264–268). Developments in the design of heavy forging presses are described and discussed.—R. A. R.

Forging Presses. M. Monsalve Flores. (Anales de Mecanica y Electricidad, 1950, vol. 26, Jan.–Feb., pp. 35–45 ; Mar.–Apr., pp. 81–90). [In Spanish]. The first part deals with the various component parts of presses, including head stocks, cylinders, columns, cross-heads, saddles, and anvils. A table gives details of diameters of pistons, and types, sizes, and lives of leathers for various sizes of press. In the second part the auxiliaries of the forging press are described.—R. A. R.

The Importance of the Guides in Tool Construction for Stamping Operations. H. Segin. (Werkstatt und Betrieb, 1950, vol. 83, Jan., pp. 29–31). The function and the importance of the guides in stamping machines are explained and some designs are described. For cutting foils and thin sheets, and for accurate deformation by stamping, guides are essential.—R. A. R.

Some Important Aspects of Scrap Allowances in Press-Shop Operations. J. A. Grainger. (Sheet Metal Industries, 1950, vol. 27, Jan., pp. 37–42). Recommendations are made on determining the spacing between blanks when these are stamped out of strip for mass-production work.—R. A. R.

Industrial Extrusion of Steel Using a Hydraulic Press. H. Steinbach. (Revue Générale de Mécanique, 1950, vol. 34, Jan., pp. 34–36). A 1500-ton hydraulic press, designed specially for the extrusion of steel tubes and shapes, is described. The press was built by the Etablissement Morane for the Comptoir Industriel d'Etirage et de Profilage des Métaux. Means of compensating the expansion of the dies are incorporated in the press. Charging of ingots is fully automatic. R. F. F.

A Note on the Correct Shape of Wire Drawing Dies. M. Schneider. (Prace Badawcze Glownego Instytutu Metalurgii i Odlewnictwa, 1949, vol. 1, pp. 213–231). [In Polish]. The theoretical principles have been studied in order to standardize the shapes and sizes of wire-drawing dies made from sintered carbides. Formulæ from the literature on drawing forces and die angles are used to explain the factors to be taken into account in the selection of die contours and sizes for particular applications. The author derives a formula and presents diagrams to facilitate the calculation of die angles.

ROLLING-MILL PRACTICE

A Graphical Analysis of Power Consumption in Hot Rolling. J. H. Mort. (Sheet Metal Industries, 1950, vol. 27, Jan., pp. 5–18, 20). Rolling-mill power curves in most cases are of two types in which h.p./hr./net-ton are plotted as ordinates against (*a*) elongations as abscissæ, or (*b*) thicknesses as abscissæ. The question whether curves, in which the power consumption per unit of weight plotted against the displacement of material in rolling, may be more reliable criteria of performance than energy-elongation curves is dealt with. The relationship of elongation to displacement is defined and it is shown how other factors such as temperature, slab volume, and slab thickness, influence the shapes of the curves.—R. A. R.

Production Efficiency in Rolling Mills. J. Rossi, jun. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Apr., pp. 145–163). [In Portuguese]. The author discusses the factors affecting the efficiency of production in the rolling mill and analyses ideal working conditions.

The six main items connected with the efficiency of rolling mills are : (1) Roll pass design ; (2) use of a minimum number of passes compatible with engine power to economize in metal heat and in rolls ; (3) efficient study of a pass schedule before planning modifications ; (4) the rolling efficiency (η) should be stated on inspection sheets. This is also useful in comparing similar mills. Metallic yield is likewise useful ; (5) a saving of 1% in rejects is equivalent to several per cent saved in rolling costs ; and (6) although wages are relatively low in Brazilian rolling mills, labour costs far exceed the total of all other costs. This indicates the need for mechanization. R. S.

The Calculation of Roll Pressure in the Rolling Mill Process. Z. Wusatowski. (Prace Badawcze Glownego Instytutu Metalurgii i Odlewnictwa, 1949, vol. 1, pp. 233–290). [In Polish]. The paper is in four parts. In Part I, on the basic principles of plastic deformation in rolling, general formulæ are developed. In Part II, on the theoretical calculation of roll pressure, several diagrams for the determination of resistance to flow in hot and in cold rolling are presented. In Part III, on the empirical calculation of roll pressure, numerous diagrams are presented for different conditions of rolling steel and non-ferrous metals. In Part IV, on the calculation of roll pressure by roll flattening and tension, the formulæ of Hitchcock, Trinks, and of Bland and Ford are considered.

Remarks on Continuous Rolling Mills. F. del Moral. (Metalurgia y Electricidad, 1950, vol. 14, Jan., pp. 62–63). [In Spanish]. The author very briefly touches on factors affecting the problem of roll design and the speed of rolls in a continuous mill and illustrates his theme with examples. R. S.

The Sendzimir Mill for Cold Rolled Strip and Sheets. T. Kessler. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Apr., pp. 241–250). [In Portuguese]. The well-known features and advantages of the Sendzimir Mill are described and a comparison is drawn with the ordinary rolling mill.—R. S.

LUBRICANTS AND LUBRICATION

Chemical Aspects of Wear and Friction. R. G. Larsen and G. L. Perry. (American Society for Metals, Conference on Mechanical Wear, June, 1948, pp. 73–94). The chemical aspects of boundary lubrication are examined in the light of results obtained with a wear-testing machine in which one ball is caused to revolve against three stationary balls under an adjustable load.—R. A. R.

Wear and Damage of Metal Surfaces with Fluid Lubrication, No Lubrication, and Boundary Lubrication. F. P. Bowden and D. Tabor. (American Society for Metals, Conference on Mechanical Wear, June, 1948, pp. 109–144). Some physical aspects of the metallic wear which may occur under different conditions of lubrication are discussed. Large forces sufficient to cause plastic deformation can be transmitted through an oil film without breaking it. Plastic deformation or work hardening beneath the metal surface may occur when there is no sliding between surfaces, but it is intensified by the sliding process, particularly if no lubricant is present. Even with the best boundary lubricant film there is still some metallic transfer through the film when sliding occurs. When metals are cut under a pool of lubricant so as to expose clean metal free from oxide, the surface is not lubricated by fatty acid solutions, and fatty acids are still generally ineffective if a dry oxide film is present.—R. A. R.

The Need for Studies of " Real " Hydrodynamic Lubrication. R. W. Dayton. (American Society for Metals, Conference on Mechanical Wear, June, 1948, pp. 165–180). The author refers to a type of lubrication called " thin-film lubrication " which falls between boundary and hydrodynamic lubrication, and shows that research on hydrodynamic phenomena in the thin-film region is needed and would be profitable.—R. A. R.

The Dielectric Strength of Oil Film in Plain Bearings. C. M. Allen. (American Society for Metals, Conference on Mechanical Wear, June, 1948, pp. 181–197). A method for estimating the minimum oil-film thickness in sleeve bearings is described. It is based on applying an electrical potential between the bearing and shaft, sufficiently high to rupture the lubricant film. As the minimum oil-film thickness fluctuates rapidly an audio-frequency oscillator was used as the voltage source ; this delivered up to 100 V. and was operated at 20,000 cycles. The breakdown voltage was measured by a

cathode-ray oscilloscope. By synchronizing the sweep frequency of the oscilloscope with the rotation of the shaft it was possible to determine the cause of thin spots in the minimum oil film, *i.e.*, whether there were high spots on the bearing surface, or on the shaft surface, or whether there was dirt in the clearance space. Dielectric breakdown was studied in the case of bearings of (*a*) 72/25/3 copper–lead–tin, (*b*) 90/10 aluminium–iron, (*c*) a babbitt metal with 90% tin, and (*d*) 80/10/10 leaded bronze, all with steel shafts. When shafts of these alloys were run against hardened steel bearings, the poorest of the bearing materials gave the best performance as a shaft.

In general, complete dielectric breakdown is a sign of approaching bearing failure. Consequently, failure can be averted by lightening the load the moment dielectric breakdown occurs.—R. A. R.

Gear Wear as Related to Viscosity of Oil. H. Blok. (American Society for Metals, Conference on Mechanical Wear, June, 1948, pp. 199–227). In the first part of the paper a 'chatter' machine is described for subjecting gear teeth to impact loads. This was used with 18 different lubricants with viscosities ranging from 68 to 776 Saybolt to demonstrate that increasing the viscosity promotes hydrodynamic cushioning of the impact loading under chattering conditions. In the second part it is shown that, with the conventional SAE lubricant testing machine, viscosity does play an appreciable part in determining the load at failure. To eliminate the effect of viscosity as a hydrodynamic factor, a new method was introduced in which the test cups were rotated at equal speeds with the adjacent surfaces in opposing directions so that the oil would not be under 'wedge action.' With the conventional tests the load-at-failure/log-viscosity curve rises sharply after a certain critical viscosity value, whereas with the new method the plot gives a straight line with a small incline.—R. A. R.

WELDING AND FLAME-CUTTING

Welding Electrodes. J. Ortega Costa. (Acero y Energia, 1950, vol. 7, Jan.–Feb., pp. 25–27). [In Spanish]. The author confines himself to a discussion of coated electrodes. He describes their nature, the triple purpose of the coating (protection, control, chemical), the action of fluxes, process of fusion, effect of heating on the zone adjacent to the weld, and the effect of varying amperage. A classification of electrodes is given and the choice of suitable electrodes is discussed.—R. S.

Weldability of Constructional Steels. L. Badias Aznar. (Boletin de Informacion del Instituto de la Soldadura, 1949, No. 5, pp. 8–17). [In Spanish]. The author first discusses solid solutions within the framework of the iron–carbon diagram. Portevin's definition of weldability in 1935 is taken as the best of many: "Weldability is the aptitude of metals and alloys for producing a continuous and compact union when subjected to the operations and regulations of arc welding." Reference is made to the threefold aspect of weldability ('operational,' 'metallurgical,' and 'constructive') studied by Séférian and Leroy. This article deals with the metallurgical aspect in relation to carbon steels, involving a study of the physicochemical modifications resulting from welding. It discusses oxidation losses; absorption of oxygen, nitrogen, and hydrogen; effect of electrode coatings on precipitation; and structural modifications in the base metal.

R. S.

International Classification of Electrodes. O. Weincke. (Dansk Teknisk Tidsskrift, 1950, vol. 74, Jan., pp. 27–31). [In Danish]. Danish proposals to the International Institute of Welding for the classification of welding electrodes are discussed.—R. A. R.

Steel Weldability Tests. F. Pobořil and F. Šícha. (Hutnické Listy, 1950, vol. 5, Jan., pp. 5–9; Feb., pp. 57–61; Mar., pp. 101–105). [In Czech]. The authors review briefly the current methods of testing the weldability of steel and describe in detail a new method based on their own experiments. This method is mainly suitable for carbon and low-alloy steels classified as not suitable for hardening, and particular attention is paid to the phenomena occurring in the transition zone of the welded specimen. The results obtained show that rapid cooling from a temperature near Ac_1 embrittles the transition zone near the weld in the case of low-carbon steels with a tendency to brittleness. The authors have developed a new weldability test on the basis of further experiments on the influence of the critical temperature just below Ac_1 and the influence of ageing. It consists of quenching the rough-machined impact test specimen in water from a temperature just below Ac_1, artificial ageing of the finish-machined specimen at 100° C. for 2 hr. and determination of the impact resistance at room temperature. The steel is classified as weldable if the impact resistance of all the three specimens $\geqslant$ 3 kg.m./sq. cm. The results of regenerative heat-treatment of artificially aged specimens are shown by micrographs.—E. G.

A Survey of Modern Theory on Welding and Weldability. D. Séférian. (Sheet Metal Industries, 1949, vol. 26, Mar., pp. 597–604; Apr., pp. 827–835; July, pp. 1511–1518, 1526; Aug., pp. 1747–1754, 1760; 1950, vol. 27, Jan., pp. 53–64). In the first part the author discusses the characteristics of oxy-acetylene, oxy-hydrogen, and hydrocarbon gas flames for welding. In the second part the technique of oxy-acetylene welding is described. The third part is devoted to metallic arc welding and metallic arcs in gaseous atmospheres; in an appendix there is a thermodynamic analysis of the atomic hydrogen flame. In the fourth part arc-welding techniques are described, and the fifth part deals with methods of making tensile, hardness, impact, and fatigue tests on welds.—R. A. R.

Metallic Tubes and Pipes. E. J. de Witt. (Ingenieria e Industria, 1949, vol. 17, Nov., pp. 58–62, 85; Dec., pp. 57–60, 80). [In Spanish]. The first part of this article classifies tubular materials and describes some processes for the manufacture of welded and seamless tubes. The second part describes methods for the production of hot-rolled and cold-drawn steel tubes and their applications. A fairly detailed classification of commercial piping is given.—R. S.

New Process for Manufacture of Large Welded Tubes. (Ingenieria e Industria, 1950, vol. 18, Jan.–Feb., pp. 106–108). [In Spanish]. The new process for manufacturing large tubes from sheet steel employs three hydraulic presses and submerged arc welding. The thickness varies from $\frac{1}{4}$ to $\frac{1}{2}$ in. and the outside diameter from $8\frac{5}{8}$ to 30 in. The equipment and its range of production are described and illustrated. The article is based on data from the Yoder Company in the U.S.A.—R. S.

High Quality Welding of Manganese Steel Tools. W. Hummitzsch and A. Schmidt. (Schweisstechnik, 1950, vol. 4, Jan., pp. 9–11). The building up of worn surfaces of manganese steel crushing machinery is discussed. It has been found that high chromium steel electrodes are best for this purpose as these form an exceedingly tough austenitic chromium–manganese steel deposit. Some examples are described.

Considerations on the Hard-Facing of Surfaces. D. B. Rankin. (Ingenieria e Industria, 1949, vol. 17, Dec., pp. 75–77). [In Spanish]. The virtues of hard-facing, particularly the saving of time in application, are reviewed generally and the question of selecting suitable materials is discussed. The quality of the deposits and the cost of the hard metal are considered briefly.—R. S.

Electric Arc Welding. T. Kitice and J. Mendes França. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, July, pp. 11–32). [In Portuguese]. Tests carried out in the laboratories of the I.P.T. (Technological Research Institute) on welded parts received from all over Brazil gave evidence of a great lack of knowledge of good welding technique. The article describes, in an elementary manner, the characteristics of welding apparatus and studies the properties of a good weld. Two examples of extremely bad welds tested by the I.P.T. are discussed.—R. S.

The Argonarc Welding Process. R. R. Sillifant and W. A. Woollcott. (Welding, 1949, vol. 17, Oct., pp. 430–441; Nov., pp. 493–506). The present position of argon-arc welding and its applications to industry are discussed. The fundamentals of the process are explained and the characteristics of D.C. and A.C. argon-shielded arcs are given. Manual and machine argon-arc welding techniques and British equipment are described.—R. A. R.

Light-Weight Steel Construction in Conjunction with the Protective-Atmosphere Brazing Process. O. Göttfert. (Die Technik, 1950, vol. 5, Jan., pp. 23–26). Examples are given of the saving in material and time which can be achieved by constructing parts of one or more pressings which are brazed together in a furnace filled with a protective atmosphere.—R. A. R.

Underwater Welding and Cutting. H. Samyn. (Boletin de Informacion del Instituto de la Soldadura, 1949, No. 5, pp. 47–55). [In Spanish]. A simple explanation of the possibility of maintaining an electric arc under water is given. The essential characteristics of electrodes and electrode holders for underwater operations are stated.

The principles of oxy-electric cutting, safety precautions, and supply of electric current, are discussed, and the main types of electrode (including Swafford and ceramic electrodes) are described. Tables give details of depth of cut, oxygen pressure at surface, speed of cutting, length of cut per unit consumption of electrode, and cutting time per meter (including change of electrode). Finally, oxy-electric cutting under water is compared with the other processes and a table summarizes the gas consumptions.—R. S.

CLEANING AND PICKLING

Descaling with Sodium Hydride. G. Stempfel. (Bulletin du Cercle d'Etudes des Métaux, 1949, vol. 5, Mar., pp. 186–190). With normal acid descaling methods, a loss of the metal underlying the oxidation layers cannot be avoided. There is also the danger of pickling embrittlenses due to the evolution of hydrogen. Sodium hydride descaling, instead of dissolving the metal oxides in acid, reduces them chemically. The affinity of sodium hydride for oxygen transforms nearly all oxides to the metal excepting chromium, for which only the sub-oxide stage is reached.

Sodium hydride pickling is carried out in a bath of molten caustic soda heated to 370–380° C. and containing in solution 1–2% of sodium hydride. The period of immersion is fairly short and is followed by water-quenching and washing. The sodium hydride is formed in the bath by placing metallic sodium in a reaction box with no bottom. Since the melting point of sodium is below 100° C., the sodium in the reaction box is in the liquid state. Hydrogen is bubbled through the sodium, and the sodium hydride formed diffuses from the reaction box into the bath. Cracked ammonia is used as a source of hydrogen. The necessary apparatus is described.

It is important to relate the cost of this method to its advantages. The cost is somewhat higher than that of acid pickling but rather lower than that of mechanical descaling. The advantages of sodium hydride are : (*a*) All ferrous and non-ferrous metals (except low-melting-point alloys) not attacked by soda can be treated ; (*b*) the higher cost is often justified by the technical advantages of the process ; (*c*) hydrogen embrittlement is avoided ; (*d*) the process is of special interest in the case of spring manufacture (where the tempering temperature is about 380° C.). Descaling and tempering operations can be combined ; (*e*) sand castings are often difficult to descale in acid because the sand adheres in hard layers. Sodium hydride pickling removes the sand as well as the oxide. Easier machining results ; (*f*) the process is rapid (few minutes to half an hour).

The author concludes with a note on the control of bath concentration based on treating the bath samples of sodium hydride with water and measuring the hydrogen evolved.

R. S.

Disposal of Waste Pickling Solutions. M. Smialowski and J. Rusz. (Prace Badawcze Glownego Instytutu Metalurgii i Odlewnictwa, 1949, vol. 1, pp. 189–194). [In Polish]. A short survey is given of methods of utilizing waste pickling liquor. The recovery of sulphuric acid and the crystallization of $FeSO_4.7H_2O$ were carried out in a vacuum crystallizer with steam injection. The second method suggested is based on concentration of the solution to $FeSO_4.H_2O$ by drying. Red ferric oxide suitable for paint manufacture can be obtained by roasting ferrous sulphate in a rotary furnace at 700° C. for 2 hr.—W. J. W.

Preparation of Pipe Surface for Bitumen Coating during Reconditioning. O. C. Mudd. (Corrosion, 1950, vol. 6, Jan., pp. 19–22). Methods of cleaning pipes, taken from the ground to prepare them for coating with bitumen, are discussed. Mechanical cleaning by machines with rotary knives, cutter wheels, or brushes, or with combinations of these, are effective but expensive. Sand-blasting is advocated. Mechanical cleaning followed by treatment with a chemical cleaning solution recommended by the bitumen suppliers is also very good.—R. A. R.

Electrolytic Polishing of Metallic Surfaces. P. A. Jacquet. (Metal Finishing, 1950, vol. 48, Jan., pp. 56–62 ; Feb., pp. 55–62). Continuation of a series of articles (*see* Journ I. and S.I., 1950, vol. 164, Apr., p. 494). In Part VI differences in the properties of surfaces polished electrolytically and by other methods are discussed. It is shown among other things,, that owing to the removal of microscratches the fatigue strength of electrolytically polished specimens is greater than that of mechanically polished specimens. The concluding part describes electrolytic polishing to obtain a superfinish, *e.g.*, to remove the burr from a dental drill, and discusses electrolytic polishing as an intermediate stage in manufacture. There is an extensive bibliography to each part.—R. A. R.

Cleaning Metal Surfaces. G. Schultze. (Werkstoffe und Korrosion, 1950, vol. 1, Jan., pp. 26–33). Pickling processes for cleaning metal surfaces are reviewed and data are presented showing the loss of weight of mild steel on different pickling solutions containing additions of inhibitors in various concentrations.—R. A. R.

Dust Extraction from the Metal Polishing Shop. C. R. Draper. (Electroplating, 1950, vol. 3, Jan., pp. 155–163 ; Feb., pp. 194–205 ; Mar., pp. 235–240). The design and efficiency of dust extraction equipment are discussed. Part I deals with hoods and ducting, Part II with separators and fans, and Part III with planning the system as a whole. In an appendix D. H. Wood makes recommendations on taking manometer readings at the end of the duct remote from the fan to comply with Factory Acts Form 89.—R. A. R.

PROTECTIVE COATINGS

Continuous Zinc Coating Units. H. W. Lynn. (American Zinc Institute : Industrial Heating, 1950, vol. 17, Jan., pp. 74–78, 174). The author reports experience gained by the Weirton Steel Company and the H. H. Robertson Company, near Pittsburgh, with the continuous hot-dip zinc coating of steel strip. At the Weirton plant the strip passes through an aqueous flux solution and then through a radiant tube furnace to dry the flux and preheat the strip before it enters the zinc bath ; the operating speed is from 120 to 240 ft./min. The H. H. Robertson Company uses the Wean Titecote lead–zinc process in which the strip passes through pickling, washing, molten lead, and molten zinc baths in succession. The strip is of 12, 16, and 18 gauge and production averages 10 tons/hr.—R. A. R.

Continuous Electrolytic Process Makes Tin Plate. (Canadian Metals, 1950, vol. 13, Jan., pp. 8–11). A brief illustrated description is given of the continuous electrolytic tinning plant recently completed at the Hamilton Works of the Steel Company of Canada. The strip passes through the tinning line at 800 ft./min. and production can reach 300 tons of finished sheets per day.—R. A. R.

The Optical Constants of Thin Metallic Films. R. Weale. (Proceedings of the Physical Society, Section B, 1949, vol. 62, Sept. 1, pp. 576–578). The optical constants of thin films are shown to depend on the thickness of the films because of the variation of the electrical conductivity with thickness. Good and bad conductors both exhibit maxima in the curves relating absorption coefficient and film thickness : in the two groups these peaks are due to two entirely different causes. The mean free paths of the conducting electrons are calculated from data found in the literature.

POWDER METALLURGY

Powder Metallurgy. J. S. Campbell. (Engineering Journal, 1950, vol. 33, Jan., pp. 10–12). The fundamental principles of the powder-metallurgy process are briefly described, and the mechanical properties of fine steel powders, one iron and an 80/20 brass fabricated by powder metallurgy are given.

R. A. R.

Survey of Powder Metallurgy Processes—Sintering. L. Auguet y Duran. (Revista de Ciencia Aplicada, 1950, vol. 4, Jan.–Feb., pp. 13–28). [In Spanish]. This part continues the survey of the sintering process by discussing the influence of the following factors : Temperature and time of sintering ; the protection of compacts ; effect of various atmospheres ; variations in composition and dimensions during sintering, and the porosity of sintered products.

A comparison of melting points and sintering temperatures of some powdered metals and alloys is given. Graphs illustrate : (1) The physical properties of electrolytic iron compacts ; (2) the influence of sintering temperature on the

density (powdered metals compressed at high pressures show little increase of density with rising sintering temperature, and if the compression pressure is very high, they may even show a decrease in density); (3) influence of sintering temperature on hardness of the metal and in relation to compression pressure and; (4) influence of the sintering temperature on the tensile strength and elongation of the sintered metal, showing areas of recrystallization and intense grain growth.—R. S.

Some Effects of Oxygen on the Performance of Iron Powder. J. J. Cordiano. (Metal Powder Association, Proceedings Fifth Annual Meeting, Apr. 5–6, 1949, pp. 20–35). Iron mill-scale (73·50% total iron) was ball-milled to a — 100-mesh powder and reduced in dry hydrogen to produce seven powders varying in oxide content, but with approximately the same physical characteristics. The effect of the different oxide contents on the properties of sintered compacts was then investigated. Internal oxides in iron powders do not materially affect the mechanical properties of sintered iron compacts, but do have a strong effect by decreasing the density of both green and sintered compacts. Both volume and linear shrinkage increase with increasing internal oxide content.

R. A. R.

Tolerances of Finished Metal Powder Parts. W. R. Toeplitz. (Metal Powder Association, Proceedings Fifth Annual Meeting, Apr., 5–6, 1949, pp. 36–50). The author discusses the tolerances within which parts made by powder metallurgy can be produced and the variables affecting them. Drawings are shown of eight parts and those dimensions where the tolerances were exceeded are pointed out. A plea is made to designers not to specify unnecessarily small tolerances.—R. A. R.

Effects of Impurities in Metal Powders. F. V. Lenel. (Metal Powder Association, Proceedings Fifth Annual Meeting, Apr. 5–6, 1949, pp. 65–73). Impurities affect not only the mechanical properties of metals and metal powder compacts, but also their chemical, electrical, and magnetic properties. Deliberate use is made of intergranular corrosion due to impurities in order to produce stainless steel powder by J. Wulff's method. Impurities affect the sintering in the presence of a liquid phase in those cases where minimum porosity is to be attained. Non-metallic impurities will interfere with the wetting of the solid particles by the liquid because the interfacial tension between the impurities and the liquid phase is lower than that between the metallic phases.—R. A. R.

Finished Stainless Powder Parts Mass-Produced in Wide Range of Shapes and Sizes. (Steel, 1949, vol. 125, Dec. 26, pp. 55–56). The Amplex Division of the Chrysler Corporation, Detroit, is now making a wide range of small parts, gears, levers, bearings, etc., from stainless steel powder. The powder, purchased from a New York chemical manufacturer, is believed to be made from stainless steel trimmings, or the scrap from blanking operations, by preferential grain-boundary attack—probably after heat-treatment to precipitate carbides. Particles are irregular in shape and size; the range employed by this firm is from 150 mesh to 1 micron (0·001 mm.). Higher compacting pressures and sintering temperatures than necessary with iron or brass powders are required with stainless steel; an average tensile strength of 15 tons per sq. in. can be attained.—J. P. S.

Cemented or Sintered Hard Carbides. V. Chiaverini. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Apr., pp. 333–359). [In Portuguese]. The Widia type of cutting material is described. After outlining the processes of manufacture, the author describes the physical properties of these materials and stresses the importance of a careful selection of the right type for a given job.

The hard carbides are classified according to their applications into four groups for: (1) Drawing and wire-drawing dies; (2) machining cast iron, non-ferrous and non-metallic materials; (3) machining steel: and (4) other purposes. The process of manufacture of the hard cutting alloys consists of five operations: (1) The production of the metallic raw materials; (2) mixing the metallic powders; (3) pressing; (4) pre-sintering; and (5) final sintering. Tests for the inspection of these materials are described.—R. S.

PROPERTIES AND TESTS

Some Effects of Austenitic Grain Size and Metallurgical Structure on the Mechanical Properties of Steel. G. M. Sinclair and T. J. Dolan. (American Society for Testing Materials, 1950, Preprint No. 15). Studies were made, using a 0·45% carbon steel and two low-alloy steels, to determine the changes in mechanical properties which accompanied a large increase in the grain size of the austenite (from A.S.T.M. No. 10 to No. 3). Each steel was heat-treated to produce two general types of microstructure, but all were tempered to about Rockwell B100.

For those cases with a microstructure mainly of tempered martensite, it was found in general that: (*a*) An increase in the previous austenite grain size slightly decreased the percentage elongation obtained in static tension tests, but did not appreciably affect the yield, tensile, or fatigue strengths, and (*b*) in the transition temperature range, the energy absorbed by **V**-notched Charpy impact specimens was somewhat greater for the coarse-grained steels.

For those cases in which the microstructure was essentially pearlitic, a large increase in the grain size of the previous austenite greatly reduced the ductility as measured by percentage elongation and also decreased the energy absorbed in the **V**-notch Charpy impact test over all ranges of temperature investigated.—R. A. R.

Reproducibility of Results of Tension Tests on Specimens Prepared from Cast Steel Coupons. H. A. Schwartz and W. K. Bock. (American Society for Testing Materials, 1950, Preprint No. 16). Data are recorded to show the degree of reproducibility of the usual static test properties of cast steel as determined on test pieces of different design. The results of single tests, or the average of a small number of tests is shown not to be an adequate measure of the mechanical properties of a given steel cast in a given form of test piece.

R. A. R.

The Influence of Strain Rate on Some Tensile Properties of Steel. D. S. Clark and P. E. Duwez. (American Society for Testing Materials, 1950, Preprint No. 17). The inability of impact tests to reveal the true influence of strain rate on the tensile properties is demonstrated. The requirements of a device to demonstrate strain rates are examined and a machine for this purpose is described. The results of static tests and of tests at strain rates up to 200 in./in./sec. on three steels are presented and discussed. The proportional limit of these steels increased to a value corresponding to the ultimate strength at a strain rate of between 40 and 80 in./in./sec. The ultimate strength of all the materials tested increased with increasing rate of strain up to a rate of about 100 in./in./sec. and then was not affected appreciably.—R. A. R.

A Method of Making Tension Specimens of Metals Using a Miniature Specimen. R. L. Templin and W. C. Aber. (American Society for Testing Materials, 1950, Preprint No. 28). Miniature tensile-test specimens 0·05 in. in dia. can be used satisfactorily for determining tensile strength, yield strength, and elongation on a gauge length of four diameters, and perhaps to find the reduction of area of at least some metals, provided that the material has a fine grain structure and its modulus of elasticity has been established.—R. A. R.

Study of Deformation at High Strain Rates Using High-Speed Motion Pictures. H. I. Fusfeld and Josephine C. Feder. (American Society for Testing Materials, 1950, Preprint No. 42). A high-speed motion-picture technique has been applied to study the change in shape of the neck when pulling 0·505-in. dia. specimens of aluminium, brass, and 0·2% cold-rolled steel. Comparison of the results with those obtained by P. W. Bridgman (*see* Journ. I. and S.I., 1944, vol. 150, p. 52A) show that the true uni-axial tensile stress during tests at strain rates of 100 and 1000 in./min. is of the order of 5% higher than would be calculated by Bridgman's results. The change in the formation of the neck with strain rate indicates the manner in which the work-hardening varies with strain rate. Steel and aluminium showed little change at 100 in./min. and more at 1000 in./min., whilst brass showed considerable change at the first speed and little more at the faster speed. The strain at which necking occurs tends to increase with increasing speed of test.—R. A. R.

The Influence of Specimen Dimension and Shape on the Results in Tension Impact Testing. D. S. Clark and D. S. Wood. (American Society for Testing Materials, 1950, Preprint No. 43). The results of tensile impact tests on cold-rolled 0·2% carbon steel and copper show that it is necessary to utilize a length/diameter ratio of approximately 13 to establish the critical velocity. The shape of the cross-section

of the specimen does not influence the effect of velocity on the tensile properties of metal within the dimensions studied. R. A. R.

A Reduction-of-Area Gage for Use at Low Temperatures. G. W. Geil and N. L. Carwile. (A.S.T.M. Bulletin, 1950, Jan., pp. 75–78). A description is given of a gauge which can be used to measure accurately the change in diameter of unnotched cylindrical specimens submerged in liquid baths during tension tests at low or moderately elevated temperatures. It can also be used for following the change in diameter of circumferentially notched cylindrical specimens during tests in tension at low or moderately elevated temperatures. J. C. R.

The Mode of Fracture at the Neck of a Tensile Specimen. W. I. Pumphrey. (Proceedings of the Physical Society, Section B, 1949, vol. 62, Oct. 1, pp. 647–651). P. W. Bridgman has shown that in a cylindrical specimen which is deforming plastically under longitudinal tension the tensile stress at the neck of the specimen is greatest on the longitudinal axis and least at the periphery. Fracture, therefore, commences at the centre and extends from there to the periphery. 'Double-cup' fractures encountered during the tensile testing of a number of alloys at elevated temperatures have been accounted for in this way, and an examination has been made of the metallurgical factors which govern the occurrence of this type of fracture.

The Study of a Dilatometric Peculiarity of Chromium–Molybdenum Steels. M. Pelabon and J. Ivernel. (Bulletin du Cercle d'Etudes des Métaux, 1949, vol. 5, June, pp. 193–208). The dilatometric curve of the chromium–molybdenum steels with the higher chromium contents, heated to 640–720° C. presents a more or less marked kink. This peculiarity has been studied in conjunction with a peculiarity in the curve for mechanical properties related to the temperature of tempering. It was traced to a transformation of retained austenite which took place at the temperature mentioned. The presence of this austenite after hardening is also revealed by a further hardening observed after tempering at a low temperature (500° C.). In this case, the residual austenite is transformed to martensite during cooling after tempering. The transformation is confirmed by the dilatometer.

It is most probable that the temperature range of this dilatometric peculiarity depends on the composition of the retained austenite, whilst its amplitude is a function of the amount of this austenite, thus varying with the factors favouring secondary hardening.—R. S.

Tensile Strength and Chemical Composition of Grey Cast Iron. E. Schmiegelow and J. Mendes França. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, Jan., pp. 27–40). [In Portuguese]. The authors describe a method of calculating (within a margin of error of 5%) the tensile strength of grey cast-iron bars of any diameter, based on a knowledge of the chemical composition and tensile strength of a test piece taken from a 30-mm. diameter bar.—R. S.

Some Considerations of the Carbon Equivalent, the Bend Test, and the Correlation between Mechanical and Chemical Properties and Practical Results Obtained with Grey Cast Iron. F. Fabriani. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, July, pp. 265–284). [In Portuguese]. The author considers the carbon concentrations in eutectic compositions expressed as a relationship between the equivalent carbon of an iron–carbon–silicon alloy and the eutectic carbon for a silicon-free alloy. A study of the correlation between mechanical tests and the chemical analyses of grey cast irons is made. Finally, cupola control by wedge tests is described. R. S.

"Transition" Temperatures under Various Amounts of Plastic Flow. N. Grossman and C. W. McGregor. (Welding Journal, 1949, vol. 28, Nov., pp. 551-s–555-s). The method used by the Massachusetts Institute of Technology for the determination of the ductile–brittle transition temperature (the M.I.T. test) indicates the highest temperature at which no macroscopic plastic flow occurs when the special slow bend test is conducted under fixed conditions of restraint and strain rate. The methods used by other laboratories, according to the authors, involve the measurement of angle of bend, lateral contraction, energy absorption, ratio of cleavage to shear fracture, and specify a temperature at which one of these criteria will be at an arbitrary value. The authors therefore have compared two different steels and two different shapes of notch in the M.I.T. test, and conclude that the absolute value of the transition temperature depends on the shape of the notch as well as on the material, and that, where a permanent angular bend of 0·5° produced fracture, the temperature at fracture was about 100° F. above the brittle transition temperature indicated by the M.I.T. test.—J. P. S.

The Natural Elasticity Constants and the Predominating (Natural) Shear Stress Direction. O. Föppl. (Mitteilungen des Wöhler-Instituts, 1949, No. 43). A general state of tri-axial principal stresses σ_x, σ_y, and σ_z can be resolved into a state of stress σ_0 in all directions and two natural states of shear stress. A mathematical treatment of this is presented. R. A. R.

Strain Gages for Large Plastic Strains and Combined Stresses. J. Marin. (A.S.T.M. Bulletin, 1949, Oct., pp. 28–31). Two specially designed strain gauges are described which are used for measuring plastic strains on tubular specimens subjected to combined stresses. One, a tension–torsion gauge, is a mechanical gauge designed to measure angles of twist and axial strains on a tubular specimen subjected to axial tension and twisting. The other, a tension–tension gauge, is a clip-type electrical strain gauge used for measuring longitudinal and lateral strains in a tubular specimen subjected to combined internal pressure and axial load.—J. C. R.

Stress Analysis of Automotive Cylinder Blocks. M. A. Erickson. (American Society for Testing Materials, Symposium on Testing of Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 2–10). The use of electrical resistance SR-4 strain gauges in determining the mechanical properties of cast iron is demonstrated. An example is given to show the application of strain gauges in the stress and strength analysis of an experimental cylinder block from a motor-car engine.—R. A. R.

Residual Stresses in Cylinder Blocks. R. J. King. (American Society for Testing Materials, Symposium on Testing of Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 11–15). Electrical resistance SR-4 strain gauges were applied to an 800-lb. grey-iron diesel engine cylinder block to study residual stresses. The inner longitudinal wall carried residual tensile stress and the outer walls were in a state of residual compression. The effects of certain variations in foundry practice are not sufficiently controllable to prevent high residual stresses.—R. A. R.

An Analysis of Locked-in Stresses in Automotive Cylinder Blocks. S. J. Stockett and H. W. Lownie, jun. (American Society for Testing Materials, Symposium on Testing of Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 16–18). Sets of electrical resistance strain gauges were fixed to different parts of a cylinder block casting (six cylinders in line) and sections containing the gauges were removed by sawing or drilling. The internal stresses were calculated from the modulus of elasticity of the cast iron and the relaxation movements indicated by the gauges. Stresses from 20,300 lb./sq. in. in tension to 7400 lb./sq. in. in compression were among the results obtained. R. A. R.

Strain Testing of Crankshafts, Engine Frames, and Cylinders. H. M. Hardy and T. O. Kuivinen. (American Society for Testing Materials, Symposium on Testing Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 21–28). Weaknesses in the design of a cast-iron crankshaft for a diesel engine with 9-in. cylinders, a cast frame for a medium-high-speed **V**-type diesel engine, and a compressor cylinder were discovered by using electrical resistance strain gauges. The stress values obtained are given and the changes in design which are intended to reduce these are described.—R. A. R.

Strain Gage Tests on Diesel Cylinder Blocks, Heads, and Pistons. C. L. Newton and J. D. Swannack. (American Society for Testing Materials, Symposium on Testing of Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 29–33). Electrical resistance strain gauges were used on the cylinder block, piston, and cylinder head of a large diesel engine to determine the approximate magnitude of stress in these parts under operating conditions, and to measure stress and deflection in the crown of the piston, as well as the stress in the cylinder head caused by tightening studs when installing the injection nozzle, air start valve, and indicator valve.—R. A. R.

Stress-Strain Tests on Rectangular Cast Iron Beams. O. Smalley. (American Society for Testing Materials, Symposium on Testing of Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 34–43). Bars of Meehanite cast iron, types GM and GA, were machined and ground to $1 \times 2\frac{1}{2} \times 36$ in. and $2 \times 4 \times 52$ in. and tested in bending by applying a load to the centre of a beam resting on rollers placed on the bar at a distance of one-third the span length from each end. Electrical resistance strain gauges were placed on all four sides of the bars. The following tentative conclusions were reached: (1) At moderate loads the modulus of elasticity is the same in tension and compression; (2) the material appears to obey Hooke's law in bending at up to about 30% of the ultimate load; (3) the strain characteristics in the transverse tests indicate the validity of the beam theory to levels of about 30% of the ultimate load; (4) the strain distribution across a section in pure bending is linear up to at least 80% of the ultimate load; and (5) the neutral axis shifts to the compression side of the beam by a maximum of about 5% of the beam depth.—R. A. R.

Stress-Strain Tests on Various Cast Iron Beam Sections. H. M. Hardy and T. O. Kuivinen. (American Society for Testing Materials, Symposium on Testing of Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 44–52). Circular, rectangular, and **I** and **T** section beams, 21 in. long, of cast iron were bent under a central load and strain measurements were made with electrical resistance strain gauges; the results are presented to show why iron has a high modulus of rupture in bending, and to study normal bending theory in the fatigue range.

Stress Analysis of a Cast Iron 125-lb. Valve Assembly. V. T. Malcolm and S. Low. (American Society for Testing Materials, Symposium on Testing of Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 53–59). To study whether cast iron could be used instead of steel for making 12-in. flanged gate valves, a cast-iron valve was tested under internal pressure and the stresses calculated from electrical resistance strain gauge readings. Many of the results are presented by graphs. The hub of the cap flange was the weakest point in the valve assembly.—R. A. R.

Stress Analysis of a Cast Iron Split Tapping Sleeve. E. C. Sears, J. W. Miner, and E. D. McCauley. (American Society for Testing Materials, Symposium on Testing of Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 60–64). Split cast-iron sleeves, used to cut into a 6-in. gas main to make a 4-in. branch connection without interrupting the service on the main, were tested under pressure by means of electrical resistance strain gauges. The results led to improvements in design which increased the bursting pressure of the sleeve by 50%.—R. A. R.

Stress Analysis of Cast Iron for Valve Parts. H. Wyatt. (American Society for Testing Materials, Symposium on Testing of Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 65–66). Cast irons which have, and have not been previously stressed behave quite differently when a load is applied. Previously stressed cast iron retains a permanent set in proportion to the original plastic deformation and the number of stress cycles; repeated restressing removes the plastic deformation and the material becomes elastic; it will then have a modulus of elasticity for each load level of stressing. Knowing the moduli, any unknown stresses can be calculated from electrical resistance strain gauge measurements. The method of making a stress analysis from strain gauge measurements on cast iron is explained.—R. A. R.

Residual Stresses in Cast Iron Deaerating Trays. J. A. Cameron. (American Society for Testing Materials, Symposium on Testing of Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 68–69). The results are presented of an investigation with electrical resistance strain gauges to determine the residual stresses in an austenitic cast iron (Si 2%, Ni 14%, Cr 2%, Cu 7%) de-aerating feed-water heater tray. Tensile stresses almost equal to the tensile strength of the material were found in certain areas; a stress-relieving heat-treatment was therefore introduced.—R. A. R.

Some Strain Gage Studies of Cast Iron Punch Press Frames. G. A. Brewer. (American Society for Testing Materials, Symposium on Testing of Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 70–72). Electrical resistance strain gauges were used to determine the strains in the cast-iron frame of a punch press to which loads of up to 30 tons were applied with a jack. At 30 tons load the stress at the platen fillet was calculated to be 23,600 lb./sq. in., that in the gibb fillet 9400 lb./sq. in.; at other parts the stresses did not exceed 4500 lb./sq. in. The frame was redesigned to have platen fillets $\frac{3}{4}$ in. instead of $\frac{1}{4}$ in. radius.—R. A. R.

Stress Determination in Cast Irons for Railroad Service. R. A. Flinn and R. J. Ely. (American Society for Testing Materials, Symposium on Testing of Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 73–85). Electrical resistance strain gauges have been used to study the effect of shape and amount of graphite, and of type of matrix on the modulus of elasticity of cast irons used in railway service. The shape and amount of graphite may normally change the modulus of elasticity from 26×10^6 to 10×10^6 lb./sq. in. The total elongation varies from 5·5 to 0·18% and the tensile strength from 78,000 to 25,000 lb./sq. in. Results of the measurement of strains during press fitting of wheels on axles, and of stress determinations after different heat-treatments are reported. The cause of cracks in a flame-hardening cylinder bore is also discussed.—R. A. R.

Location and Measurement of Stresses in Gray Iron Tractor Castings. H. Bornstein. (American Society for Testing Materials, Symposium on Testing of Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 86–89). Brittle lacquer coatings and electrical resistance strain gauges were employed to locate and measure peak stresses in a gear casting fixed to a shaft with a set screw, and in a drive sprocket. Illustrations show the stress pattern obtained. By allowing cast-iron wheels to cool in the mould instead of being shaken out while red hot, the residual stresses were reduced from about 28,000 lb./sq. in. to below 10,000 lb./sq. in.—R. A. R.

Stress-Strain Studies of Cast Iron for Textile Machinery Parts. V. E. Hillman. (American Society for Testing Materials, Symposium on Testing of Cast Iron with SR-4 Type of Gage, June, 1949, Special Technical Publication No. 97, pp. 90-92). Strain-strain curves for specimens $\frac{3}{4}$ in. in dia. of three cast irons, used in the manufacture of looms, are presented. Data from electrical resistance strain gauge tests show the increase in compressive stress in the flanges of a warp roll as the amount of material wound on it increases.—R. A. R.

BL-310 "Strain Analyzer." D. Christian. (Proceedings of the Society for Experimental Stress Analysis, 1949, vol. 7, No. 1, pp. 21–29). Engineers have expressed their desire for a direct inking oscillograph combined with a bridge amplifier which would instantly and accurately record strains. This paper describes the problems involved in the design of a strain gauge system to make instantaneous recordings of static strains, and of dynamic strains at up to 120 cycles/sec. The problems discussed include bridge construction, attenuation, amplifier construction, phase-sensitive detection, and direct-coupled amplifier design. The resulting instrument is described and its characteristics given. An example of its use is the recording of the transfer of the oscillation of one of a pair of equal-sized cantilever bars to the other when both are fastened to a common angle bracket and one is vibrated.—R. A. R.

Experimental Determination of Metal Drawing and Forming Forces. A. R. Kimbell. (Proceedings of the Society for Experimental Stress Analysis, 1949, vol. 7, No. 1, pp. 51–60). The author discusses the application of wire strain gauges to the problem of measuring loads on cupping and redrawing dies and presents some of the results. In making a $\frac{1}{4}$-in. cupped nut from blanks of 0·05-in. thick 0·10% carbon steel in a 50-ton mechanical press the blank is cupped, piloted, redrawn six times, the radius joining flange to barrel is coined out, the bottom is perforated and countersunk, the flange is embossed, and the part is trimmed. The six redraws contributed most to die wear. The load characteristics of the six redraws were investigated by means of electrical resistance strain gauges attached to a tool steel load column inserted beneath, and directly bearing on, the die insert. These were connected to a bridge amplifier and oscillograph. The load characteristics of each redrawing operation are analysed and show that, as regards tool wear, the most important period

is that when the drawing load starts to increase after the first point of contact. At this period the increasing load acts on a small area and tends to break down the oil film. R. A. R.

A Biaxial Stress Machine for the Determination of Stress-Strain Relations. J. Marin. (Proceedings of the Society for Experimental Stress Analysis, 1949, vol. 7, No. 1, pp. 71–82). A biaxial stressing machine and strain-measuring equipment are described. The biaxial stresses are both tensile; they are produced by subjecting a tubular specimen to a combination of internal pressure and axial tension. Strains are measured in the plastic range by specially designed SR-4 electric resistance strain gauges. Results are given for tests on an aluminium alloy tube.—R. A. R.

Fatigue Life of Rail Webs in Service. C. J. Code and A. E. F. Billstein. (Proceedings of the Society for Experimental Stress Analysis, 1949, vol. 7, No. 1, pp. 103–116). The occurrence of cracks along the lower part of the fillet between web and head of flat-bottomed rails (131 lb./yd.) after short service led to an investigation of this defect on rails in use and in the laboratory. The equipment, incorporating electrical resistance strain gauges, amplifiers, and an oscillograph is described. Several stages in the development of the cracks are illustrated. A new rail section with a greater fillet radius was designed, and fatigue and corrosion-fatigue tests to determine its probable life were made; these are also reported. R. A. R.

Influence of the Elastic Constants on the Partition of Load between Rivets. W. D. Mitchell and D. Rosenthal. (Proceedings of the Society for Experimental Stress Analysis, 1949, vol. 7, No. 2, pp. 17–26). Strain gauges have been used to measure elongations of joints in mild-steel plates consisting of two $\frac{1}{4}$-in. cover plates on one $\frac{1}{2}$-in. plate joined by drilling with $\frac{3}{8}$-in. holes in line and fitted with carefully machined pins of steel, aluminium alloy, brass, and leucite. Several joints were prepared with a different number of pins per joint—at working loads such pins behave in the same way as rivets. Normally, the first and last rivets in a line carry most of the load. It was found that to improve substantially the load distribution, the rivets or pins must have a rigidity at least one-tenth of that of the joined members.—R. A. R.

Energy Losses and Fracture of Some Metals Resulting from a Small Number of Cycles of Strain. T. E. Pardue, J. L. Melchor, and W. B. Good. (Proceedings of the Society for Experimental Stress Analysis, 1949, vol. 7, No. 2, pp. 27–39). A rotating-beam fatigue machine was used at 72 r.p.m. to make preliminary observations of the behaviour of mild steel, stainless steel, copper, and aluminium when subjected to repeated loads sufficiently high to produce failure in the range below 10,000 repetitions of strain. Stress/number-of-cycles curves were obtained which show the relative strengths of the materials under these high loads. The variation in the energy dissipated during the test was obtained from the lateral deflection of the specimen. From this the total energy dissipated during the life of a specimen was observed to increase as the load was decreased.—R. A. R.

New Developments in Dynamic Strain Recording Equipment. C. M. Hathaway. (Proceedings of the Society for Experimental Stress Analysis, 1949, vol. 7, No. 2, pp. 119–126). The basic principles employed in dynamic strain-recording equipment have not changed, but many detailed improvements and circuit modifications have resulted in increased accuracy and stability of the new instruments. This paper points out the latest improvements, describes the latest designs, and outlines the applications and limitations of the more modern equipment.—R. A. R.

Stresses in Keyways by Photoelastic Methods and Comparison with Numerical Solution. M. M. Leven. (Proceedings of the Society for Experimental Stress Analysis, 1949, vol. 7, No. 2, pp. 141–154). By means of numerical solutions of the stress function differential equation, the shearing stresses in keyways in shafts subjected to torsion have been accurately evaluated for five ratios of keyway fillet radius to shaft diameter. These same shearing stresses have then been obtained by photoelastic tests employing several different methods in an attempt to check their validity. The maximum shear stresses in keyed shafts subjected to pure torsion have a maximum value at the keyway fillet, and vary from twice the nominal shear stress with a small semi-circular keyway to about four times the nominal shear stress when the fillet-radius/shaft-diameter ratio is 0·005.—R. A. R.

Efficient Measures of Ductility and Capacity for Deformation of Metals. W. Grundig. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, Jan., pp. 68–91). [In Portuguese]. The author explains the true significance of ductility and capacity for deformation of metals in relation to their behaviour under service conditions of static and linear stress. The relationship between the resistance to deformation and the rupture strength, and between elongation and reduction of area are considered. Since these relationships are difficult to determine experimentally, and the elongation and reduction of area do not express true deformations and are dependent on length of tests and shape of test piece, the true elongations are given together with the true transverse contractions as determined in the classic tensile test. The capacity for deformation is the sum of these two types of deformation.

Metallurgical Examination of a Marine Engine Oil-Pump Spindle. A. H. da Silveira Feijo, S. M. Lobo Radino, and E. G. de Andrade. (Revista de Química Industrial, 1950, vol. 19, Jan., pp. 18–23). [In Portuguese]. The authors describe results of a macro- and micro-examination, analysis, and hardness test on a broken oil-pump spindle from a marine engine, sent to the Metallurgical Industries Division of the Spanish National Institute of Technology. The spindle was made from case-hardened steel (C 0·24%, Si 0·27%, Mn 1·04%, P 0·025%, S 0·032%, Mo 0·11%). Examination showed that the fracture was probably due partly to the presence of cementite in the case-hardened region and partly to the rather large grain size of the martensite of the core. R. S.

Dimensional Considerations in Friction and Wear. C. F. Taylor. (American Society for Metals, Conference on Mechanical Wear, June, 1948, pp. 1–7). The symbols used in the papers presented at the Conference are explained, technical terms are defined, and some fundamental mathematical relations are shown.—R. A. R.

Wear in Diesel Engines. C. G. A. Rosen. (American Society for Metals, Conference on Mechanical Wear, June, 1948, pp. 8–16). The factors influencing the wear of cylinders, piston rings, crankshaft, and journals of diesel engines are discussed. Aspects requiring further investigation are pointed out; these include: (*a*) How corrosion affects normal wear; (*b*) selection of material for the oil-control piston ring; and (*c*) the nature of the small proportion of dust passing through air filters. In wear tests on a 0·45% carbon steel in the annealed, spheroidized, and martensitic states the spheroidized steel was the least resistant to wear.—R. A. R.

Wear of Automotive Engine Cylinders and Piston Rings. P. S. Lane. (American Society for Metals, Conference on Mechanical Wear, June, 1948, pp. 17–46). The manner in which wear is affected by cylinder block design, metal structure, precision boring of cylinders, and mechanical and chemical surface finishes to cylinder bores is discussed in the first part. In the second part, on piston-ring wear, the effect of different types of compression ring and oil ring are dealt with. The author holds that a good piston-ring structure is one which will continually wear or change in dimension, always presenting a new adjustable surface to the bores. R. A. R.

Fuel and Lubrication Factors in Piston Ring and Cylinder Wear. A. G. Cattaneo and E. S. Starkman. (American Society for Metals, Conference on Mechanical Wear, June, 1948, pp. 47–72). Techniques for experimental wear testing for cylinders and piston rings are discussed. Wear data obtained by averaging the results of tests on a number of similar engines are less significant than those obtained by averaging data from a succession of runs on the same engine. The influence of the temperature of the cooling medium and the lubricating oil, and the corrosive wear from sulphur and halides are also considered.—R. A. R.

Wear in Steam Turbines. N. L. Mochel. (American Society for Metals, Conference on Mechanical Wear, June, 1948, pp. 145–164). The positions in large and small steam turbines which are particularly subject to wear and the measures taken to obtain longer life are discussed, special attention being given to seals and glands.—R. A. R.

Surface Deterioration of Gear Teeth. J. O. Almen. (American Society for Metals, Conference on Mechanical Wear, June, 1948, pp. 229–288). The forms of gear teeth wear are briefly described and some instances of contact welding referred to. Formulæ used in automotive gear design are discussed at

length. It is shown how to compute the susceptibility to welding. Ideal gear lubrication would consist of a dry housing and jets to spray the lubricant over the teeth just after they come out of mesh. Long experience indicates that pitting fatigue will not occur in gears of automotive hardness at theoretical compressive stresses at the pitch line up to 220,000 lb./sq. in. Investigations of residual stresses at increasing depths in gear teeth are also reported.—R. A. R.

Recent Roll Tests on Endurance Limits of Materials. E. Buckingham and G. J. Talbourdet. (American Society for Metals, Conference on Mechanical Wear, June, 1948, pp. 289–307). The many different conditions observed during roll-wear tests are described and illustrated. These tests were performed in a machine in which test rolls from 2·2 to 3·5 in. in dia. with a face of 1 in. max. are driven by gears to give pure rolling or combined rolling and sliding. Loads up to 5000 lb. could be applied by means of a calibrated spring. Load/number-of-cycles curves are presented, and the types of damage are shown in many illustrations.—R. A. R.

Hardness and Its Influence on Wear. R. Holm. (American Society for Metals, Conference on Mechanical Wear, June, 1948, pp. 309–329). The theory of contact hardness is surveyed. Curves are shown for the hardness of work-hardened copper plotted against specific depth of impression; the measured points obtained with different sizes of ball arrange themselves fairly well along single curves which are characteristic for the material under test. These curves are expressed by an equation containing a few constants. The second part of the paper deals with the principles for correlating measurements of frictional wear. When a sliding part glides on a base plane, the moving atoms in the contact surface encounter stationary atoms in the latter, and a fraction Z of these encounters may result in the abrasion of single atoms from the base plane. It is shown that the function Z enables one to make a good survey of wear measurements with different loads, and it indicates whether the wear is atomic or not.—R. A. R.

Summary of Factors in the Wear Process. J. T. Burwell, jun. (American Society for Metals, Conference on Mechanical Wear, June, 1948, pp. 359–369). In making a general survey of the papers presented at the Conference, the author remarks that they testify clearly to the extremely composite nature of wear and suggests systematizing the problem by dividing the factors entering into the wear process into the three categories primary operating conditions, intermediate factors, and manifestations of wear. The author considered that surface hardness, lubricant viscosity, and chemical interaction were well covered by the Conference, but the factors of metallurgy, elasticity, and surface finish should receive more attention.—R. A. R.

A New High Frequency Machine for the Fatigue Testing of Metals. R. Jacquesson and P. Laurent. (Revue Générale de Mécanique, 1950, vol. 34, Jan., pp. 31–36). The principles and description are given of a fatigue-testing machine designed to investigate the behaviour of materials subjected to alternating stresses of high frequency (*i.e.*, 5000–60,000 cycles/min.). Four types of stress can be applied with this machine: Alternating torsion, pulsating torsion, alternating bending, and pulsating bending. The amplitude of the oscillations can be varied even while the test is in progress.—R. F. F.

Effects of Grinding and other Finishing Processes on the Fatigue Strength of Hardened Steel. L. P. Tarasov and H. J. Grover. (American Society for Testing Materials, 1950, Preprint No. 18). The effect of grinding on the fatigue strength of a ball-bearing steel (C 1·00%, Cr 1·40%, V 0·20%) at Rockwell hardness levels of C45 and C59 was investigated. The direction of the grinding scratches was always parallel to the specimen length. Reversed-bend tests on flat bars showed: (1) The endurance limit after gentle grinding was as high as after gentle grinding and polishing; (2) severe grinding reduced the endurance limit about 20–25%; and (3) either tumbling or shot-blasting after grinding greatly increased the endurance limit. Endurance limits of round bars were affected little by surfacing processes.—R. A. R.

The Question of the Effect of Surface Pressure on Fatigue Strength. A. Eichinger. (Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, Jan., 11, pp. 35–39). The literature on the effects of cold deformation and residual stresses on fatigue strength is reviewed and the results of many tests are cited and discussed. The increase in fatigue strength which is obtained by pressure-rolling the surface of a shaft is not due to any single cause, but to a combination of causes and conditions among which are the residual stresses, the quality and shape of the material, its previous history, and the type of fatigue stress applied.—R. A. R.

Modern Conceptions of Hardening and Hardenability. L. H. Acera. (Instituto del Hierro y del Acero, 1950, vol. 3, Jan.–Mar., pp. 30–38). [In Spanish]. Modern ideas on hardening, the Jominy test and hardenability are surveyed, simply and briefly. Ideal hardening and the ideal diameter are defined and tables and graphs are given for the calculation of the latter as a function of the percentage of carbon and austenitic grain size.—R. S.

Tests for Hardenability and Resistance to Grain Growth of 1% Carbon Steels. (Bulletin du Cercle d'Etudes des Métaux, 1949, vol. 5, June, pp. 209–219). Following the standardization of the hardenability and grain-growth test for carbon tool steels, it was desired to ascertain the degree of consistency of results from different casts in one works and from casts in different works.

Tests were carried out on 20-mm. dia. bars from seven works. Samples were treated at 760°, 790°, 820°, 850°, and 880° C. and immersed in a salt bath. The bars were notched and fractured (opposite the notch) in a static bend test. To determine depth of hardening, the face of each fracture was polished with 00 emery and exposed for 3 min. in an aqueous solution of 50% HCl heated to 80–85° C., washed in warm water, and dried with compressed air. Results showed considerable variation from cast to cast. There was no general correlation of variation of grain size and depth of hardening.
R. S.

Applications and Analysis of Methods of Determining Rockwell Hardness. E. Orosco. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Jan., pp. 3–38). [In Portuguese]. An investigation is made of the relationship between the varying conditions of testing and the hardness values. The formula obtained is based on Meyer's law and was confirmed by practical tests on various metals. The author calculates the degree of permissible error in the load and in the diameter of the impression and introduces a conception of sensitivity. A new design for Rockwell machines is indicated.
R. S.

Rockwell C Hardness on Cylindrical Steel Specimens. F. W. Hussey. (American Society for Testing Materials, 1950, Preprint No. 20). Over 2800 individual hardness readings were made on the flat and curved surfaces of carefully prepared steel specimens of small diameter to determine the deviations of readings on curved surfaces from those on 'true' values of flat areas. Eighty steel specimens of eight diameters were turned down from larger stock, heat-treated to obtain ten ranges of hardness in each group, and carefully ground to a fine surface finish. Correlation curves are presented which may be used to obtain actual Rockwell C hardness values from measurements made on cylindrical surfaces of the following diameters: $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$, $\frac{7}{8}$, 1, and $1\frac{1}{4}$ in.—R. A. R.

Technique of Rockwell Hardness Testing. E. Orosco. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, July, pp. 546–557). [In Portuguese]. The author studies the relationship between the Rockwell hardness values and the distance between the impression and the edge of the specimen. It was found that this distance did affect the test results and a formula is suggested to relate the critical distance x, the diameter D of the cone indenter, and the hardness value R.—R. S.

Correlation between Different Hardness Scales for Grey Cast Iron. J. Wozniacki. (Prace Badawcze Glownego Instytutu Metalurgii i Odlewnictwa, 1949, vol. 1, pp. 203–211). [In Polish]. Tables and graphs are presented for correlating the hardness of grey cast iron as measured by different scales, and equations for conversion are proposed.

Microhardness Testers. R. Mechling. (Métallurgie, 1950, vol. 82, Jan., pp. 47–51; Feb., pp. 115–121). The nature and applications of microhardness testing are explained. Research in this field is reviewed. The various scratch and static penetration methods are described and compared.

The necessity of operating microhardness testing methods away from vibration, and the degree of preparation required in preparing the samples are drawbacks to the wider use of this method of hardness testing under works conditions.

The author suggests standardizing on certain loads and on tolerances for the diamond points used.—R. S.

White Magnetic Fluid. (Iron and Steel, 1950, vol. 23, Jan., p. 12). A new fluid developed by Metropolitan-Vickers Electrical Co., Ltd., for magnetic crack detection is described (*see* Journ. I. and S.I., 1950, vol. 165, July, p. 359).—R. A. R.

Energy Loss in the Processes of Magnetization of Magnetic Sheet. S. Velayos, M. P. Andrés, and V. S. Giron. (Revista de Ciencia Aplicada, 1950, vol. 4, Jan.–Feb., pp. 1–13). [in Spanish]. The total losses due to hysteresis and Foucault currents were determined in magnetic sheet subjected to alternate magnetic fields of frequencies ranging between 25 and 60 cycles/sec., and with maximum magnetic inductions varying between 5000 and 12,000 gauss.

Three different sheets were tested, two of Spanish and one of foreign make. The wide frequency interval enabled an approximate value for hysteresis loss to be determined by extrapolation, based on the experimental results for total losses. The hysteresis losses thus obtained are similar to those directly determined by a totally different method. Special attention is given to the measurement of the form factor of the alternating current used, as this value enters into the expression of the maximum magnetic induction to which the material is subjected.—R. S.

Modern Magnetic Alloys and Their Application. E. Steinort. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1950, vol. 5, Jan. 31, pp. 15–19). The properties of several permanent magnet alloys, including Ticonal (Ni 14%, Co 24%, Al 8·5%, Cu 3%, Ti 0·5%, balance Fe) and Cuniko (Cu 45%, Ni 25%, Co 30%), are presented and discussed, and recommendations on the design of magnets for specific purposes are made.—R. A. R.

The Magnetostriction of Anisotropic Permanent Magnet Alloys. M. McCaig. (Proceedings of the Physical Society, Section B, 1949, vol. 62, Oct. 1, pp. 652–656). Blocks of permanent magnet alloys of the system Fe–Ni–Al–Co–Cu have been prepared with columnar crystals. The magnetostriction has been measured in various directions before and after heat-treatment in a magnetic field. The results agree well with those predicted theoretically, and so confirm the postulated crystal structure.

Losses in Electrical Sheet Steel. K. H. Stewart. (Symposium of Ferromagnetic Materials, 7–8 Nov., 1949: Proceedings of the Institution of Electrical Engineers, 1950, vol. 97, Part II, Apr., pp. 121–125). Various experiments on the magnetic losses in sheet steel at power frequencies and flux densities are described and their interpretation is discussed. It is concluded that an important fraction of the total loss in low-loss sheet cannot be accounted for by the normal hysteresis and eddy-current mechanisms, or by modifications of the latter to allow for non-uniformity of the permeability. This extra loss seems to be due to the finite velocity of domain wall movements, but it is not clear what mechanism limits this velocity; microscopic eddy currents induced by the wall movement are suggested as a possible cause.

Some Metallurgical and Structural Factors Affecting Properties of Soft Magnetic Materials. W. F. Randall and H. H. Scholefield. (Symposium on Ferromagnetic Materials, 7–8 Nov., 1949: Proceedings of the Institution of Electrical Engineers, 1950, vol. 97, Part II, Apr., pp. 133–140). The considerable effect of metallurgical factors on magnetic properties is illustrated by reference to untreated and fully processed nickel–iron and silicon–iron alloys. The factors considered are composition, *i.e.*, major constituents and heterogeneity, purity or differences in ultimate composition, non-metallic inclusions, strain content, structural orientation, grain size and grain shape, lattice ordering, magnetic domain orientation, surface conditions, and dimensional effects. These are defined and their incidence and control in manufacture discussed with particular reference to their effect on magnetic properties. The influence of the above factors on the magnetic properties, saturation intensity, maximum permeability or permeability at the knee of the B/H curve, initial permeability or threshold magnetization, D.C. hysteresis loop, particularly coercivity and remanence, total loss under A.C. magnetization at power frequencies, and permeability and loss under A.C. magnetization at high frequencies is considered. The fact that they affect the various magnetic properties in different ways so that production methods have to be adjusted accordingly is emphasized.

The Measurement and Calculation of Pulse Magnetization Characteristics of Nickel Irons from 0·1 to 5 Microseconds. W. S. Melville. (Symposium on Ferromagnetic Materials, 7–8 Nov., 1949: Proceedings of the Institution of Electrical Engineers, 1950, vol. 97, Part II, Apr., pp. 165–198). This paper describes in detail some aspects of work undertaken on the measurement of pulse magnetization characteristics of core materials. Methods and techniques of measurement in the range of pulse durations of 0·1–5 microseconds are discussed and a description is given of apparatus and some measuring components which were used in carrying out tests on three relevant core materials. The materials are Radiometal, Rhometal, and Mumetal, in carefully prepared samples wound from rolled strip having thicknesses of 0·001–0·010 in. Pulse permeability and loss characteristics for several pulse durations and values of D.C. polarizing field are shown on curves. The effects of these variables on pulse performance are discussed. A conception of the mechanism of pulse magnetization is described and a method derived for determining analytically the theoretical magnitude of eddy currents and losses for any form of pulse which can be represented by a finite number of linear voltage changes. Results obtained by this method are compared with practical values.

The Incremental Magnetic Properties of Silicon–Iron Alloys. R. O. Carter, and D. L. Richards. (Symposium on Ferromagnetic Materials, 7–8 Nov., 1949: Proceedings of the Institution of Electrical Engineers, 1950, vol. 97, Part II, Apr., pp. 199–214). The fundamental considerations involved in defining the incremental magnetic properties of a material are briefly reviewed, and methods of measuring the properties are described. Measured values at 50 and 800 cycles/sec. for the various grades of hot-rolled silicon–iron in common use are tabulated. These measurements were obtained on samples representing the best and the worst (as judged by total power loss at 50 cycles/sec. and magnetic flux density of 10,000 and 13,000 gauss) for each grade of material, specially selected from production by the manufacturer. It is shown that the apparent reluctance of a magnetic circuit, with an air-gap which is optimum for the particular conditions of incremental magnetization, can be related to the apparent polarizing magnetizing force by an empirical equation. This equation is sufficiently accurate for most practical applications, and its use enables a purely analytical method of design of air-gapped smoothing choke to be evolved. Formulæ are developed for designs where the polarizing current and incremental inductance, together with either the D.C. voltage drop or the temperature rise, are specified. Typical values of design parameters used in actual manufactured chokes are given. For comparison, a small number of measurements of incremental properties of two grades of nickel–iron are included in an appendix.

Routine Testing Equipment for Transformer Steels. N. F. Astbury, T. Emmerson, and J. McFarlane. (Symposium on Ferromagnetic Materials, 7–8 Nov., 1949: Proceedings of the Institution of Electrical Engineers, 1950, vol. 97, Part II, Apr., pp. 221–228). The application of an A.C./D.C. null wattmeter method of iron testing to routine work is described. The wattmeter circuit is incorporated with computing networks so arranged that the work of the operator is confined to the insertion of basic data and the establishment of a series of four null balances. Use is made of an A.C. peak fluxmeter in establishing the conditions of test, and compensation is made automatically for circuit losses and air-flux corrections. The method of setting up and of calibration is briefly described.

Some Properties and Tests of Magnetic Powders and Powder Cores. C. E. Richards, S. E. Buckley, P. R. Bardell, and A. C. Lynch. (Symposium on Ferromagnetic Materials, 7–8 Nov., 1949: Proceedings of the Institution of Electrical Engineers, 1950, vol. 97, Part II, Apr., pp. 236–245). The sections of this paper deal with manufacture of materials, core manufacture, the theory of magnetic properties of powder-cores at low flux densities, apparatus used for making measurements, the determination of core losses, and the measurement of permeability and magnetic stability. The magnetic properties of a number of materials are summarized.—J. C. R.

The Detection of Cracks and Flaws in Axles and Crank Pins by Means of Supersonic Waves. G. W. C. Hirst. (Journal of the Institution of Locomotive Engineers, 1949, vol. 39,

July–Aug., pp. 367–385). The theory of the transmission and reflection of supersonic waves through solid bodies is explained, and a simplified diagram of the electrical circuit which initiates and records such waves is given. Examples are then described and illustrated of the types of wave-reflection diagram obtained on the screen of the cathode-ray tube when a locomotive crank pin and railway wagon axles, with saw cuts at different positions to represent cracks, were tested by the supersonic apparatus.—R. A. R.

Supersonic Crack Detection in Metallic Materials. M. Torrado Varela and M. M. Alvaro Periane. (Tecnica Metalurgica, 1949, vol. 5, July, pp. 257–265). [In Spanish]. The article relates to work carried out in the Elizalde S.A. laboratories with the Mark II-B supersonic detector built by Henry Hughes and Son, London. A brief survey is given of piezo-electric quartzes. The Hughes detector is described and some practical considerations, including surface preparation, are given. Oscillograms obtained during the installation and calibration of the detector in the Elizalde laboratories are reproduced. Finally, some of the data obtained by the Hair Line Cracks Sub-Committee of The Iron and Steel Institute in its report of March, 1946, are given, and the Spanish Iron and Steel Institute is invited to study the process of supersonic crack detection with a view to drawing up specifications and guiding principles for industry.—R. S.

The Damping Properties of Carbon Steels when Stressed in the Elastic Deformation Range. E. Diepschlag and H. Müller. (Archiv für Metallkunde, 1949, vol. 3, Nov., pp. 400–406). After discussing the fundamentals of damping and briefly reviewing several methods of measuring it, the results of tests of the damping of torsional oscillations are presented and discussed. The tests were made on 11 steels with carbon in the 0·02–0·93% range, in the as-delivered, annealed, and overheated (at 1200° C.) states. A distinction must be made between damping in the plastic and elastic deformation ranges, and at stresses close to the elastic limit. In plastic deformation the damping phenomena are governed by the fact that internal molecular friction transforms the oscillation energy into heat and the energy available to the oscillating system is correspondingly reduced. In elastic deformation the governing factor is the condition of internal stress set up in the material because of the restricted flow of individual crystallites in the matrix. The yield point represents a state of transition between these two. The type of structure and the grain size have the greatest effect on damping capacity. In the range of plastic deformation under stresses near the yield point the ferritic steels have the greatest damping capacity. Damping attains a maximum value when the proportion of pearlite has increased up to about 65%; it then decreases as the steel becomes 100% pearlitic. Annealed pearlitic steels have the greatest damping capacity.—R. A. R.

X-Rays in Industry. J. Batlle Gayan. (Acero y Energia, 1950, vol. 7, Jan.–Feb., pp. 8–14). [In Spanish]. The author summarizes the history of X-ray development and discusses the penetrability of X-rays. A brief outline is given of their application to metallurgy and the advantages arising from their use. Some practical examples are described of the determination of internal defects. Finally, there is a brief note on the photographic materials used in radiography. The aim of the article is to interest readers in the possibilities of X-ray applications in metallurgy.—R. S.

Gamma Ray Inspection of Metals. C. de Revorêdo Barros and V. Lo Ré. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Jan., pp. 36–49). [In Portuguese]. Following a brief note on radium as a source of gamma rays, the technique of gamma radiography is described. A comparative study of X-rays and gamma rays was made in the laboratories of the Institute of Technological Research in São Paulo.—R. S.

Radiography in the Steel Foundry. R. M. Landis. (American Foundryman, 1950, vol. 17, Jan., pp. 58–61). The interpretation of radiographs of castings is discussed with examples, and radiography as a means of controlling repairs by welding, and melting practice are considered.—R. A. R.

Review of the Requirements of Heat-Resisting Steels and the Solutions Possible at the Present Time. F. Rapatz. (Archiv für Metallkunde, 1949, vol. 3, Nov., pp. 387–393). Methods of testing heat-resisting steels at high temperature are briefly discussed, and the high-temperature properties of a number of high-alloy steels and hard metals are reviewed. R. A. R.

Hot Working—Desirable Qualities in Tool Steels. H. Carr. (Iron and Steel, 1950, vol. 23, Jan., pp. 3–7). The properties required in a hot-working steel are examined and suggestions are made as to existing and new laboratory tests which would promote a better understanding of these properties. Evidence is cited which indicates that the familiar heat-checking or crazy cracking on steel plugs used for piercing is probably due to ordinary thermal expansion stresses than to stresses arising from heating and cooling through the transformation range. Resistance to hot notched-impact is important in hindering the propagation of heat-checking. Tungsten hot-work tool steels should be preheated before commencing hot-working operations. Methods of measuring hot hardness, hot strength, and thermal conductivity are critically reviewed. Damping capacity increases with temperature and this effect may be a controlling factor in the fatigue and creep resistance of steel.—R. A. R.

Hardened Alloy Steel for Service up to 700° F. G. V. Smith, W. B. Seens, and E. J. Dulis. (American Society for Testing Materials, 1950, Preprint No. 36). The results of tests on the mechanical properties of two low-alloy steels (*A*: C 0·40%, Ni 1·82%, Cr 0·82%, Mo 0·24%; *B*: C 0·40 %, Ni 2·0%, Cr 0·97%, Mo 0·37%, V 0·18%) at temperatures ranging from − 315° F. to + 700° F. are reported. Although the two steels were of approximately equal yield and tensile strength at room temperature, steel *B* was slightly stronger at 700° F.—R. A. R.

Hardening of Austenitic Stainless Steels by Mechanical Working at Sub-Zero Temperatures. N. A. Ziegler and P. H. Brace. (American Society for Testing Materials, 1950, Preprint No. 39). It has been found that austenitic stainless steels of compositions in the range chromium 12–30% and nickel 11–20% can be made unusually hard by plastically deforming them at sub-zero temperatures and thus promoting the $\gamma \rightarrow \alpha$ transformation. The hardness thus obtained can be further increased by a subsequent ageing heat-treatment at about 400° C. Samples of suitable composition have been hardened right through by rolling or wire-drawing. The other physical properties are affected accordingly. Strip of 18/8 stainless steel rolled at − 185° C. had a Vickers hardness of 607 and a tensile strength of 295,000 lb./sq. in.—R. A. R.

Some Notes on the Structure and Impact Resistance of Columbium-Bearing 18-8 Steels after Exposure to Elevated Temperatures. W. O. Binder. (American Society for Testing Materials, 1950, Preprint No. 44). The influence of columbium on the impact resistance of steel containing 18% of chromium and 8 to 16% of nickel with 0 to 3% of columbium has been studied. Adding more than 2% of columbium decreases the toughness of the steel in the annealed condition due to the formation of the carbide M_6C and the compound Fe_2Cb_2. Prolonged heating at 650° and 870° C. has no significant effect on the impact resistance of steels containing up to 2% of columbium, but it is more detrimental to higher columbium steels. Positive X-ray identification of sigma phase was obtained after prolonged heating at 650° C. over the 8–16% nickel and 0·75 to 3% columbium ranges. Cold-working, followed by low-temperature annealing, accelerates the rate of precipitation of sigma phase and favours grain growth, whereas high-temperature annealing inhibits these. The precipitation of sigma phase in a critical particle size is believed to have a beneficial effect on creep strength.—R. A. R.

The Effect of Environment on the Stress-Rupture Properties of Metals at Elevated Temperatures. O. C. Shepard and W. Schalliol. (American Society for Testing Materials, 1950, Preprint No. 58). Stress-rupture tests have been made with low-carbon steels and Hastelloy C in controlled atmospheres. Small differences in the composition of the atmosphere produced fairly large differences in the amount of intergranular cracking and in the time to failure.—R. A. R.

Special Alloys for Parts Subjected to High Temperatures. R. Altamira. (Maquinas e Metais, 1950, Jan., pp. 21–23). [In Spanish]. This brief article considers four groups of alloys for high-temperature service, namely, nickel–chromium–cobalt–iron, nickel–chromium–iron, cobalt–chromium–molybdenum, and chromium–nickel.

Tables of analyses are given, and the influence of the alloying elements is outlined.—R. S.

Special Steels and Alloys for High Temperatures. E. Siebel and N. Ludwig. (Konstruktion, 1949, vol. 1, pp. 13–26: Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, Jan. 11, pp. 52–53). The properties of several high-alloy steels and one or two non-ferrous alloys for applications where it is necessary to resist temperatures in the 400–750° C. range are reviewed.—R. A. R.

Contribution to the Study of the Influence of Microstructure on the Hot Strength of Steel. G. Delbart and M. Ravery. (Instituto del Hierro y del Acero, 1950, vol. 3, Jan.–Mar., pp. 2–22). [In Spanish]. The authors discuss work done by the Institut de Recherches de la Sidérurgie de France (IRSID) Creep Testing Committee on chromium–molybdenum steel made in the basic electric arc furnace to the following analysis: C 0·12%, Si 0·16%, Mn 0·7%, Cr 0·6%, Mo 0·65%, P 0·02%, S 0·01%, and deoxidized in the ladle by additions of 0·351 kg./ton of pure titanium, 1·705 kg./ton of silicon and 0·366 kg./ton of aluminium. Details of grain size, transformation points, hot tensile strength, and **S** curves are given.

Hardness tests following each isothermal hardening are summarized to show the variations in structure in relation to time. A table is given showing structures resulting from various heat-treatments. Hardening was effected after austenitizing at 900° and 1200° C. to obtain two distinct austenite grain sizes.

Variations in the creep rate between the 25th and 35th hours were determined at 450°, 475°, and 500° C. at 24, 21·5, and 19 kg./sq. mm. respectively. It was found that the rate of creep was greater for the structures containing granular ferrite than for the structures containing no ferrite or with acicular ferrite. Of two identical structures obtained from different austenitizing temperatures, that formed from the lower temperature (*i.e.*, with finer grain) had the faster rate of creep. Creep tests at 525°, 550°, and 575° C., at 15, 11, and 7 kg./sq. mm. respectively, also showed the creep rate to be greater for the finer-grained structures.

The load corresponding to the 'Veritas' limit (*i.e.*, the load for which a creep rate of 5×10^{-4}%/hr. is obtained between the 25th and 35th hour) was determined for each structure at each of the six temperatures. It was shown that the resistance to a rise in temperature is greater the higher the temperature of decomposition of the austenite. The results of long-time creep tests (1000 hr. at 450° and 575° C. and 380 hr. at 525° C.) are discussed in relation to the various structures.

Finally, reference is made to 'new precipitates' observed following creep, sometimes within the grains and sometimes on the grain boundaries. From the practical point of view, it was unsafe to assert, generally, that any one structure was to be preferred. For resistance to creep at low temperatures, the homogeneous bainitic structure is favourable. At higher temperatures, granular ferrite is, perhaps, better. Sorbite resists fairly well at low temperatures but has a higher rate of creep at high temperatures.—R. S.

A Method of Fitting the Andrade Creep Equation to Experimental Results. A. J. Kennedy. (Proceedings of the Physical Society, 1948, vol. 61, Dec. 1, pp. 510–515). A method is described whereby the constants in Andrade's formula, $l = l_0(1 + \beta t)e^{kt}$, for the flow of metals under constant stress, can be rapidly deduced from experimental results by direct reading from a system employing sliding templates of calculated shape. The general equation to which the method is applicable is deduced.

X-Ray Study of the Sigma Phase in Various Alloy Systems. P. Duwez and S. R. Baen. (American Society for Testing Materials, 1950, Preprint No. 47). A critical review of the X-ray diffraction data of the sigma phase in the binary alloys of iron, cobalt, nickel, chromium, and vanadium is presented. Although the crystal structure of the sigma phase is still unknown, a tentative tetragonal unit cell is suggested to describe the structure, at least as a first approximation. On the basis of this cell the lattice parameters of the various binary sigma phases are computed. The case of a ternary sigma solid solution in the iron–chromium–molybdenum system is also discussed, and the influence of molybdenum on the lattice parameter of the sigma phase is described. A short discussion is given on the occurrence of the sigma phase in binary alloys and its relation to atomic diameter and crystal structure of the two component metals.—R. A. R.

Identification and Mode of Formation and Re-Solution of Sigma Phase in Austenitic Chromium–Nickel Steels. E. J. Dulis and G. V. Smith. (American Society for Testing Materials, 1950, Preprint No. 50). A comprehensive investigation of the several phases occurring in austenitic stainless steels, supplemented by X-ray diffraction and magnetic permeability studies, has suggested procedures by which the sigma, carbide, and ferrite phases can be differentiated, with certain exceptions, under the microscope. The mode of formation and re-solution of the sigma phase was observed, and transient formation of ferrite was detected during re-solution of sigma phase at a temperature above its stable range.—R. A. R.

Sigma Phase in Several Cast Austenitic Steels. V. T. Malcolm and S. Low. (American Society for Testing Materials, 1950, Preprint No. 51). Three cast 18/8 and three cast 16/35 chromium–nickel steels were investigated with respect to the embrittling effect of sigma phase after exposure to temperatures in the 1000–1500° F. range. This was done by Charpy impact tests at both room and elevated temperatures, and by metallographic and X-ray diffraction techniques. It was clearly established that the embrittling phase present in the 18/8 steels was the sigma phase, but this could not be conclusively identified in the 16/35 steels.—R. A. R.

Sigma Phase and Other Effects of Prolonged Heating at Elevated Temperatures on 25 per cent Chromium, 20 per cent Nickel Steel. G. N. Emmanuel. (American Society for Testing Materials, 1950, Preprint No. 52). The factors influencing the formation of sigma phase in 25/20 chromium–nickel steel have been investigated. When the annealed alloy is held for prolonged periods at temperatures in the range 1100–1600° F. the sigma phase forms directly from the austenitic matrix. The phase forms more rapidly and over a wider temperature range (1000–1600° F.) in the cold-worked than in the annealed alloy. Sigma-phase precipitation proceeds at an increasing rate with rising temperature, reaching a maximum at 1500° F., and then, however, decreasing to zero at 1700° F. An initially coarse-grained alloy exhibits a marked resistance to sigma formation. The impact strength is the most significant indicator of the pressure of this phase. The toughness of the most severely embrittled samples was restored by holding at 1875° F. for 2 hr. and quenching in water. Prolonged heating at 1800°, 1900°, and 2000° F., respectively, indicated that no appreciable grain growth takes place in this alloy until a temperature exceeding 1800° F. is attained.—R. A. R.

The Formation of Sigma Phase in 17 per cent Chromium Steel. J. J. Heger. (American Society for Testing Materials, 1950, Preprint No. 53). By using cold-work and extended heating periods at 900°, 1050°, and 1200° F., sigma phase was formed in a commercial 17% chromium steel. At 900° F. this phase was precipitated as particles too finely dispersed to be identified. The present iron-rich boundaries of the alpha plus sigma region in the iron–chromium diagram must be shifted to lower chromium contents.—R. A. R.

The Problem of Hydrogen in the Production of Steel. L. Coêlho Corrêa da Silva. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Jan., pp. 39–64). [In Portuguese]. A condensation of the principal themes in the literature on hydrogen in steel is made. The following aspects are covered: Absorption of hydrogen by the solid and liquid metal; formation of defects due to hydrogen during and after solidification; elimination of hydrogen during open-hearth and electric furnace production of steel, and elimination of hydrogen by cooling below the solidus line. The theory of hydrogen precipitation within the solid metal is treated simply and generally. The nature of hair-line cracks is not considered in detail.—R. S.

Effect of Elements on the Properties of Steel Castings. J. Vazquez Lopez. (Anales de Mecanica y Electricidad, 1950, vol. 26, Jan.–Feb., pp. 21–34). [In Spanish]. The effects of niobium and nickel on the properties of steel castings are discussed.—R. S.

The Effect of the Copper Content on the Mechanical Properties of Steel Sheets. F. Eisenkolb. (Die Technik, 1950, vol. 5, Jan., pp. 13–15). As open-hearth furnace charges in Germany contain a high proportion of scrap, some of which is copper-bearing, it was of interest to investigate the effect of copper on the properties of steel sheets. The previously imposed limits of 0·5% max. copper in sheets for ordinary drawing

operations and 0·3% max. for deep-drawing appear to be justified.—R. A. R.

Some Properties of Iron Made in the Catalan Forge. F. A. de Toledo Piza. (Revista de Química Industrial, 1950, vol. 19, Jan., p. 30). [In Portuguese]. This note refers to an article in the A.B.M. (Brazilian Association of Metals) Noticario 1, 4, 5, 1947. After describing the manufacture of iron in the Catalan furnace, the author gives details of mechanical tests, chemical analysis and metallographic examination of a sample bar of this Catalan iron.—R. S.

Engineering Applications of Ductile Cast Iron. A. P. Gagnebin, K. D. Millis, and N. B. Pilling. (Machine Design, 1950, vol. 22, Jan., pp. 108–114). Some applications of cast iron with the carbon in spherical form are described and discussed; they include a hydraulic press cylinder, a compressor head, a worm-wheel drive, a plough share, and a large anvil of about 9 tons.—R. A. R.

Cast Irons for Resistance Elements. L. A. de Lacerda Santos and T. Kitice. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, Oct., pp. 461–476). [In Portuguese]. The question of selecting the most promising types of cast iron for resistance elements is considered. The tendency of the Institute of Technological Research (I.P.T.) in São Paulo was to concentrate on the two best alloys, namely, Ni–Resist, and high-phosphorus cast iron. In such small sections it is possible that the relatively high phosphorus content does not increase brittleness.

Experiments were carried out to compare the electrical properties of these resistance elements. The results were as follows:

	Ni-Resist	High-Phosphorus Cast Iron
Total resistance in ohms at 21° C.	0·190	0·131
Resistivity in ohms per meter	0·910	0·620
Resistivity in ohms per circular mil inch	765	521

The choice of a suitable alloy for a given purpose depends on the particular working conditions.—R. S.

Influence of Vacuum Melting on the Properties of 25% Chromium Alloys. (Bulletin du Cercle d'Etudes des Métaux, 1949, vol. 5, Sept.–Dec., pp. 221–236). The object of this study was to examine the action of vacuum melting, under easily reproducible conditions, on the following properties of 25% chromium ferritic alloys: Analysis; mechanical properties; corrosion resistance; behaviour after prolonged heating at 475° C., especially as regards brittleness; and resistance to scaling at high temperature.

The author discusses the experimental methods; conditions of degasification; influence of vacuum melting on properties following treatment at 900–1200°, 500°, and 400° C.; and susceptibility to intercrystalline corrosion. Considerable modifications in properties were observed. When made by vacuum melting, these brittle metals acquire considerable toughness. The lowering of the carbon content (0·002–0·003% in these experiments) and good deoxidation are the two essential conditions for improving strength. High strength is maintained after prolonged heatings at high temperatures, *e.g.*, 1200° C. It was not possible, however, to avoid a decrease in strength after prolonged heating at 400–500° C., but static brittleness was avoided in the metal which had been suitably deoxidized, denitrided, and decarburized.

Scaling tests showed that vacuum melting improves the tensile strength and eliminates the harmful effects of carbon, oxygen, and nitrogen. Metallographic examination showed the formation of heterogeneity of composition after heating above 950° C. due to the unequal distribution of chromium and carbon between the ferrite and the intergranular austenite. This phenomenon was revealed by a sensitivity to intergranular corrosion and by chemical and thermomagnetic analysis.

Vacuum melting in magnesite crucibles enables raw materials containing a high percentage of carbon to be used, but has the disadvantage of producing a metal less deoxidized which makes it difficult to avoid brittleness after prolonged heating at 475° C.—R. S.

Graphitic Steels. T. Kitice. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Apr., pp. 273–290). [In Portuguese]. The author makes a preliminary study of the stability of cementite and considers the influence of composition on the nature of graphitization. The mechanism of graphitization and some metallographic aspects are considered. Properties of graphitic steels, intermediate between those of cast irons and steels, and some applications of these steels for dies, pneumatic hammer pistons, and abrasion-resisting parts are indicated.—R. S.

Ferromanganese Alloys. Austenitic Manganese Steels. C. Bradaschia. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Apr., pp. 251–272). [In Portuguese]. The article forms a general study of the iron–manganese and iron–carbon–manganese alloys and a more detailed study of the austenitic manganese steels of the Hadfield type. Physical and chemical properties of the latter and the use of nickel to retard the decomposition of austenite are discussed. The effect of chromium and copper additions to these manganese steels is also explained. Some notes are included on the field of application of manganese steels.—R. S.

Pseudo-Flakes in High Speed Steels—Their Origin and Effects on Hardness. E. Orosco. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, July, pp. 300–332). [In Portuguese]. Several test bars of wolfram high-speed steels revealed bright, coarse-grained areas in the fractures after hardening.

'Marble fractures', or pseudo-flakes in high-speed steels are due to the exaggerated growth of the austenite grain obtained by hardening. The author propounds his own theory of the formation of flakes based on his own observations, and points out where his results differ from the conclusions in the literature up to 1946.—R. S.

Cast Iron for Glass-Forming Moulds. L. A. de Lacerda Santos. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Apr., pp. 177–185). [In Portuguese]. Ideal properties for cast irons for glass moulds are stated. The processes of casting and the influence of the various components in the cast iron are described. The iron (C 3·4%, Si 2·0%, Ni 2·0%, V 0·2%) was made in electric furnaces. The Brinell hardness, after annealing at 750° C. was 140. Each mould yielded 150,000 units.—R. S.

A Classification and Description of Nickel Steels. H. Allyn Hunnicutt. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Jan., pp. 94–116). [In Portuguese]. This classification of nickel steels is based on papers which the author has translated from English. Nickel steels are classified according to methods of manufacture, structure, alloy content, finish, and applications. The effects of alloying elements in nickel steels are explained and there is much information on mechanical properties.—R. S.

Contribution to the Study of the Standardization of National (Brazilian) Pig Irons. F. Bocciarelli. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, July, pp. 523–527). [In Portuguese]. The author summarizes the discussions at the Second Annual Meeting of the Brazil Society of Metals relating to the proposed standardization of Brazilian pig irons. A classification based on silicon, manganese, and carbon contents is suggested.—R. S.

METALLOGRAPHY

Exhibition of Micrographs of the Asociación Italiana de Metalurgia. (Boletin de Informacion del Instituto de la Soldadura, 1949, No. 5, pp. 4–7). [In Spanish]. Seven micrographs prepared by Instituto Cientifico Tecnico Ernesto Breda, Milan, are reproduced. They show: (1) An arc weld of mild-steel sheet (C 0·23%); (2–5) arc welds of 0·09% C and 0·23% carbon steel sheets; and (6–7) a 0·90% carbon steel decarburized in a current of hydrogen.

The films show the evolution of the grain from the base metal through the transition zone, to the weld metal.—R. S.

Applications of Metallography to Common Steels and to Some Types of Ternary Alloy Steels. J. Oliveira Nascimento. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, Oct., pp. 113–136). [In Portuguese]. The author summarizes known conceptions with a view to clarifying relationships between microscopic aspects of carbon and alloy steels and their analyses. The effect of alloy additions on mechanical, electrical, and chemical properties is discussed.—R. S.

The Principles of Phase-Contrast Microscopy. K. J. Habell. (British Iron and Steel Research Association, Conference on the Examination of Metals by Optical Methods, May, 1949, pp. 7–11). With the phase-contrast microscope, details of a

transparent object which differ only in thickness or refractive index, and not in opacity, appear in the image as differences in brightness. A brief outline is given of the functions of the optical elements of the microscope, leading to a consideration of the diffraction theory of image formation, and to the diffraction patterns produced by amplitude and phase gratings. The action of the phase-changing plate is discussed, and its application to the phase-contrast microscope is described.—R. A. R.

Phase-Contrast Metallography. D. McLean. (British Iron and Steel Research Association, Conference on Examination of Metals by Optical Means, May, 1949, pp. 12–14). Experience with the phase-contrast microscope at the National Physical Laboratory over the last two years is discussed with examples. Examination shows that with small carbide particles which project above the surface level of the ferrite matrix, the resolution for normal and for phase-contrast illumination is about the same. However, for depressions below the surface level, *e.g.*, pits, or cementite in a ferrite matrix etched electrolytically with chromic acid, the phase-contrast illumination gives better effective resolution.

R. A. R.

Stop-Contrast. A. F. Hallimond. (British Iron and Steel Research Association, Conference on Examination of Metals by Optical Means, May, 1949, pp. 15–20). If the phase plate above the objective in the phase-contrast microscope is replaced by a simple transparent annulus surrounded by an opaque diaphragm, it will completely intercept the deviated light which misses the annulus and the wedge-shaped objective, and instead of appearing bright, as in the microscope at ordinary full aperture, it will be darkened. A considerable proportion of the objective, preferably the outer zone, must be left open or the image will lose definition. The method can be applied to polished surfaces to reveal areas that are not quite parallel to the general level. The effect is grey rather than black, but bears a general resemblance to that given by phase-contrast.—R. A. R.

The Reflecting Microscope. R. L. Drew. (British Iron and Steel Research Association, Conference on Examination of Metals by Optical Means, May, 1949, pp. 21–24). The principles of the reflecting microscope are explained with special reference to the work of Dr. Burch.—R. A. R.

Metallurgical Applications of the Reflecting Microscope. K. W. Keohane. (British Iron and Steel Research Association, Conference on Examination of Metals by Optical Means, May, 1949, p. 25). A metallurgical investigation has now been started with a new 0·65 numerical aperture reflecting microscope. Magnifications of the order of × 750 could be obtained with the microscope demonstrated. The instrument has a long working distance (14 mm.) and achromatic properties ; the former characteristic suggests the possibility of a hot stage, and the latter the possibility of ultra-violet study. Oxide coatings on polished molybdenum have been photographed up to white heat without loss of definition ; four of these photographs showing dendrites of molybdenum oxide are reproduced.—R. A. R.

A Dutch Reflecting Microscope. F. Hekker. (British Iron and Steel Research Association, Conference on Examination of Metals by Optical Means, May, 1949, pp. 26–27). An explanation is given of the principles and advantages of microscopes in which a spherically curved concave mirror is the main part of the optical instrument. A mirror microscope with a numerical aperture of 0·20 is described.—R. A. R.

A Reflecting Microscope Using Spherical Surfaces. W. E. Seeds. (British Iron and Steel Research Association, Conference on Examination of Metals by Optical Means, May, 1949, pp. 27–28). The author describes briefly how he and Dr. Wilkins have constructed a reflecting microscope. They found that it is possible to construct one from any pair of spherical surfaces the radii of which have a ratio between 3·5 : 1 and 2·5 : 1, provided that the position of the mirrors is adjusted on an interferometer to give minimum aberration. The optimum reflector is an objective of numerical aperture 0·6, and focal length of 5 mm. The objective works at a normal tube length, and fits a standard microscope giving × 36 primary magnification.—R. A. R.

High-Temperature Microscopes. H. T. Heal. (British Iron and Steel Research Association, Conference on Examination of Metals by Optical Means, May, 1949, pp. 29–32). The author describes the optical system of the high-temperature microscope under construction in the B.I.S.R.A. laboratories.

R. A. R.

The Principles of Multiple-Beam Interference Methods. S. Tolansky. (British Iron and Steel Research Association, Conference on Examination of Metals by Optical Means, May, 1949, pp. 33–40). A number of different optical systems are used in multiple-beam interference methods of examining surfaces. The author describes a simple system using monochromatic light, and a more complex one using white light. Illustrations show many of the results obtained.—R. A. R.

Some Metallurgical Applications of Multiple-Beam Interference. J. Holden. (British Iron and Steel Research Association, Conference on Examination of Metals by Optical Means, May, 1949, pp. 41–44). Examples are shown of some of the results obtained when examining aluminium, cadmium, and tin surfaces by multiple-beam interference methods, and these are discussed.—R. A. R.

Further and Future Applications of Interferometry. D. G. Nickols. (British Iron and Steel Research Association, Conference on Examination of Metals by Optical Means, May, 1949, pp. 45–47). An abrasion test developed in conjunction with the Diamond Research Laboratory is referred to, and interference fringes are shown which were produced in martensite by a cast-iron wheel charged with diamond dust.

R. A. R.

The Structure of Alloys and the Electronic Theory of Metals. L. Cintra do Prado. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, Oct., pp. 435–460). [In Portuguese]. The author thinks that physical metallurgy may soon reach the stage where it is possible to predict precisely the necessary alloy composition for given service conditions. He reviews the following themes : Determination of crystalline structures ; structure of solid solutions ; atomic diameters ; valency electrons ; electronic concentration and its relation to structures ; border regions in the equilibrium diagrams for copper and silver alloys ; Heisenberg's principle of indeterminate structures and the Fermi and Dirac statistical laws of the distribution of electrons ; and application of wave mechanics to electronic theory. The survey is based largely on British, German, and American work.—R. S.

Applied Macro- and Micro-Examination. H. Colpaert. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, Oct., pp. 137–156). [In Portuguese]. Various examples of A.S.T.M. reception tests on wagon axles, tractor caterpillars, boiler tubes, and gear wheels are described. Macro- and micro-examination of the causes of rupture, and heterogeneity are used to supplement the tests—R. S.

Metallographic Identification of Magnetic Phases. Eleanor M. A. Harvey. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Apr., pp. 291–296). [In Portuguese]. The article describes the electromagnetic apparatus used in the Brown-Firth laboratories and the preparation of specimens for the micro-examination of magnetic phases.—R. S.

A System of Classification for the Micrographic Textures of Metallurgical Products. H. Colpaert. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Apr., pp. 377–389). [In Portuguese]. The author attempts to classify the micrographic textures of steels and cast irons in order to combine in a simple manner those which reveal similarities. This facilitates a study of the relationships between these textures, the properties of the materials, and the treatments to which they have been subjected. Numbers are used to indicate the micrographic constituents and letters to illustrate their distribution, location, form, and size. Numerous examples are given.—R. S.

Report of Subcommittee XI on Electron Microstructure of Steel. (American Society for Testing Materials, June, 1950, Preprint No. 103, pp. 5–53). A series of pieces of a eutectoid steel, heat-treated to specific microstructures, were distributed among several co-operating laboratories for investigation by electron microscopy in order to determine the degree of consistency of the results and the effects of the etching and replica techniques employed. In particular, fine pearlite, bainite, and tempered martensite were studied. Forty-seven light and electron micrographs are reproduced. It was shown that replica techniques are capable of yielding true high-fidelity pictures of steel microstructures. Among the specific conclusions were : (1) In specimens of eutectoid steel transformed at 1100° F. portions of the field unresolved by the

light microscope were shown to be pearlite of very small interlamellar spacing. (2) Eutectoid steel transformed at 950° F. contains two distinct microstructures, very fine pearlite and upper bainite. (3) The microstructure of the upper bainite formed at 750° F. consists of discrete, chunky, cementite platelets, more or less randomly distributed in the ferrite matrix. The predominant length of these platelets is 10,000 Å., but there are many small cementite particles of the order of 600 Å. (4) The microstructure of lower bainite formed at 500° F. consists of ferrite bands containing small cementite platelets in parallel array. (5) In brine-quenched martensite, even very small areas of retained austenite are clearly delineated. (6) The appearance of the extremely fine martensite tempered at 400° F. suggests that carbide particles have started to precipitate at this temperature. (7) The microstructure of martensite has been completely resolved; it consists of small discrete carbide platelets in a ferrite matrix, many of the particles are as small as 300 Å. (8) The microstructures of martensite tempered at 800° F. and at 600° F. are quite similar, except that in the former considerable coalescence of the carbide particles has occurred. There is evidence that spheroidization has begun at 800° F. (9) Spheroidization of the carbide particles in martensite tempered at 1100° F. is essentially complete.—R. A. R.

The Electrolytic Polishing of Metal Surfaces and Its Significance in Microhardness Testing. K. Longard. (Archiv für Metallkunde, 1949, vol. 3, Nov., pp. 381–386). Investigations have been made with the object of determining the optimum operating conditions for the electrolytic polishing of pure aluminium, Duralumin, Armco iron, and steel. With iron and steel, care must be taken to prevent the accumulation of heat at the centre of the specimen. A microhardness tester has been used to compare the hardnesses of mechanically and electrolytically polished specimens. The results showed that the softer the initial state of the metal, the greater was the work-hardening induced by mechanical polishing. Electrolytic polishing is therefore the better method of preparation, especially for soft metals.—R. A. R.

Superlattice Structures of the Crystalline State. F. F. Pereira Pinto. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, July, pp. 285–312; Oct., pp. 674–676). [In Portuguese]. Spectrograms are given to illustrate the formations of superlattice structures in solid solutions of iron–aluminium and copper-gold alloys.

The phenomenon of the formation of superlattice structures is mainly of theoretical value. A typical problem relating to conditions of dynamic equilibrium of crystalline structures is considered. A detailed study of the process of crystallization, starting from the gaseous state, is made. Elementary notions of the geometry of crystals are stated. Modern theories relating to the formation of superlattice structures are reviewed. The author describes his own experiments in the Massachusetts Institute of Technology to confirm these theories.—R. S.

The Theory of Segregation. H. Klemm. (Archiv für Metallkunde, 1949, vol. 3, Nov., pp. 376–380). An attempt is made to explain the mechanism of segregation, especially segregation from the unstable state, on the basis of precipitation theories. Formulæ for expressing elementary and critical segregation processes are developed.—R. A. R.

Influence of Chemical Composition of Hypo-Eutectoid Steels on the Ac_3 Temperature and on the Optimum Hardening Temperature. F. Šícha. (Iron and Steel Institute, 1950, Translation Series, No. 405). This is an English translation of a paper which appeared in Hutnické Listy, 1949, vol. 4, June, pp. 169–174. *See* Journ. I. and S.I., 1950, vol. 165, May, p. 123.

On the Behaviour of Metals during Rapid Heating and Rapid Cooling. S. Sakui. (Journal of the Scientific Research Institute, 1950, vol. 44, Jan., pp. 87–101). An apparatus is described with which thin wire specimens of different metals could be heated and cooled at extremely rapid rates and the changes in electrical resistance could be followed by a cathode-ray oscillograph; these changes were converted into changes in the heating and cooling rates. The apparatus was used to study the transformation of austenite in steels with up to 1·2% of carbon. In general, two types of transitional structure were noted which could be identified by etching and by difference in hardness. One had a Vickers hardness of 400–550, and the other of 950–1000.—R. A. R.

Transformation Diagram of Grey Cast Iron. F. D. Homem de Melo. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Apr., pp. 360–376). [In Portuguese]. The author studies the transformations which occur in the cooling of grey cast iron in a mould. The influence of the rate of cooling on the properties of the structural components is indicated and the importance of the time–temperature diagram is explained.

By a combination of the **S**-curves and the Laue diagram of the formation of graphite, the author attempts to clarify the formation of the structural components in relation to different rates of cooling.—R. S.

CORROSION

The Primary Process in Corrosion. H. Grubitsch. (Archiv für Metallkunde, 1949, vol. 3, Nov., pp. 394–396). Adsorption phenomena have been investigated with a view to establishing whether they govern the initiation of corrosion. The electrochemical laws still apply in that the adsorption-active points on the metal surface become the local cathodes and anodes.—R. A. R.

Mechanism of Oxygen Reduction at an Iron Cathode. W. A. Patrick and H. B. Wagner. (Corrosion, 1950, vol. 6, Jan., pp. 34–38). The mechanism of the anodic corrosion process is discussed with special reference to the formation of hydrogen peroxide as an intermediate product. A cell was devised in which a platinum wire cathode was immersed in distilled water saturated with oxygen, and an iron wire wound round a glass frame was immersed in three different electrolytes: (*a*) dilute H_2SO_4, *p*H 4·25, (*b*) sodium sulphate, *p*H 6·5, and (*c*) dilute NaOH, *p*H 11·1. The greatest yields of hydrogen peroxide were obtained with the alkaline solutions and at small current densities. The results indicate that in any oxygen–iron corrosion process where an electrochemical mechanism is involved, hydrogen peroxide rather than the hydrogen ion should be considered as the primary cathodic reaction product.—R. A. R.

Some Notes on the Local-Cell Corrosion Theory. G. Masing. (Archiv fur Metallkunde, 1949, vol. 3, Oct., pp. 343–346). The corrosion theories of K. Wickert and of the U. R. Evans school are critically examined. The author finds a reason for the apparently contradictory nature of some of their results in the fact that in Wickert's tests (*see* Journ. I. and S.I., 1948, vol. 158, Feb., p. 285) the two specimens were connected by lifting devices of very high resistance.—R. A. R.

Recent Results in the Electrochemistry of Metallic Coatings. K. Wickert. (Archiv für Metallkunde, 1949, vol. 3, Oct., pp. 346–353). The author critically reviews the following aspects of chemical and electrochemical corrosion: (1) The nature of corrosion; (2) free and bonded electron transfer; (3) formation of local cells; (4) characteristics of the De la Rive and the Evans cells, and cells with direct electron transfer; (5) effect of the surface condition; (6) laws of the nitrogen–oxygen chain, and the Evans theory; (7) principal and subordinate local cells; (8) corrosion passivity and activity; (9) pickling inhibitors; (10) theory of the galvanic elements; (11) the disappearance of metal and the periodic system and catalysis; and (12) Hume-Rothery phases, Zintl compounds, and Laves phases.—R. A. R.

Causes and Prevention of Corrosion. F. J. Maffei. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, July, pp. 419–441). [In Portuguese]. The article is confined to electrochemical corrosion and the main factors favouring it are considered. Finally, the various methods of combating corrosion, including the use of surface coatings and inhibitors, and the additions of other metals are described.—R. S.

Present State of the Problem of the Oxidation of Metals. J. Benard. (Bulletin du Cercle d'Etudes des Métaux, 1949, vol. 5, Mar., pp. 173–185). Whilst there is an abundance of technical data on the scaling of metals at high temperatures as regards the practical solution of problems of oxidation, there is a dearth of information on the reactions produced at the surface of heat-resisting alloys. The author deals with the oxidation of pure metals and of alloys.

In studying the kinetics of the reactions of oxidation, the author considers the total quantity of oxygen taken up by the metal in relation to time. The problem of scaling at temperature can be approached from two angles: (1) A study of the kinetics of the oxidation reactions at different

temperatures whereby the amount of oxygen taken up by the metal surface after a given period of exposure is determined and the variations in this quantity are related to time; and (2) the chemical composition, micrographic appearance, and crystal structure of the oxide layer are examined and the relationships between these characteristics and the structure of the underlying metal are established. This type of research on pure metals has provided certain guiding principles regarding the mechanism of oxidation. The mechanism of diffusion in oxides and the effect of structure on the rate of oxidation are examined.

Empirical rules for determining the approximate analysis of iron–nickel–chromium alloys to resist dry corrosion under given conditions are summarized.

The author suggests the following broad lines of future research on the scaling of alloys: (*a*) A study of the refractory character of the fundamental binary systems; (*b*) a study of the nature of the oxides formed on the surfaces of these alloys under greatly varying conditions; and (*c*) a study of the diffusion of the different kinds of ions in the oxides.—R. S.

Coal-Ash Corrosion of Metals at Elevated Temperatures. C. T. Evans, jun. (American Society for Testing Materials, 1950, Preprint No. 55). An investigation was conducted with S-588 heat-resisting alloy (C 0·42%, Mn 1·50%, Si 0·80%, Ni 20·31%, Cr 18·38%, W 3·08%, Mo 4·18%, Cb 4·69%) in order to observe the corrosion of the alloy at 1350° F. in contact with raw coal ash from Illinois coal. This and some other alloys were all unaffected by the coal ash.—R. A. R.

Effect of Adsorbed Polar Organic Compounds on Activity of Steel in Acid Solution. N. Hackerman and E. L. Cook. (Journal of the Electrochemical Society, 1950, vol. 97, Jan., pp. 1–9). When aliphatic acids, amines, and esters were adsorbed from benzene solution on to 0·20% carbon steel powder, some portion of the sorbed material, depending on the compound, could not be desorbed by fresh solvent. The work here reported is concerned with the effect of the adsorbed material on the activity of the steel powder in aqueous HCl. The ratio of this activity to that of untreated steel powder depended on the compound adsorbed and the type of adsorption. In general, the acids and amines were considerably more effective as inhibitors than the alcohols and esters; the order of their effectiveness was about the same as the order of adsorption from benzene.—R. A. R.

The Cost of Corrosion to the United States. H. H. Uhlig. (United Nations Sectional Meeting, Mineral Resources, Sept., 1949: Corrosion, 1950, vol. 6, Jan., pp. 29–33). Estimates are presented of the cost of corrosion to the United States. The losses (estimated at an annual cost of over $5500 million) are divided into indirect losses, losses incurred by allowing increased weight of material to provide for corrosion, and direct losses. A formula for determining whether the use of a more costly or protective coating to increase the life of a structure is economic is presented, and the cost of cathodic protection for buried pipelines and other metal structures is considered. Finally, the need for research is stressed.—R. A. R.

Boiler Corrosion and Boiler Feed Water Treatment. H. Hillier. (Transactions of the Institute of Marine Engineers, 1950, vol. 62, Jan., pp. 1–42). The fundamental factors of the electrochemical action which causes corrosion and the principal types of corrosion inside boiler equipment are described and illustrated. It is shown that the vital factors in boiler corrosion are the hydrogen ion concentration and the presence of dissolved oxygen. The physical facts concerning hydrogen ion concentration and the removal of dissolved oxygen are discussed and equipment for providing feed water free from oxygen is described and illustrated. The factors affecting the electrode potential of iron and the conditions necessary to obtain immunity from corrosion, also the conditioning of boiler water to prevent the formation of scale are dealt with. R. A. R.

Fundamental Questions on the Importance of Oxygen in the Treatment of Water and Protection against Corrosion. L. W. Haase. (Werkstoffe und Korrosion, 1950, vol. 1, Jan., pp. 4–9). The differences between 'old' water which has had time to take minerals into solution and reach a state of equilibrium, and 'fresh' water which has not had time to do this are discussed with special reference to the oxygen content and the corrosion of water mains. Methods of determining the oxygen content are described and experiments on the rate of oxygen absorption are cited. The latter showed that an oxygen content of about 0·003 g./c.c. is reached very quickly, but above this concentration the saturation value is approached asymptotically. The removal of iron and manganese and the equilibrium between the contents of organic matter and oxygen are then dealt with. It is shown that it is insufficient to remove the iron and manganese compounds and the excess CO_2, because measures must be taken to maintain a high enough oxygen concentration to form a continuous protective coating of oxide on the inside of the water mains to prevent further corrosion.—R. A. R.

Corrosion and Protection of Mine Hoist Ropes. F. L. LaQue. (American Society of Lubrication Engineers: Corrosion, 1950, vol. 6, Jan., pp. 8–13). Illustrations of sections of corroded and worn mine-hoist ropes are presented and the causes of failure discussed. Fatigue cracks in the outer wires lead to failure more often than do corrosion pits or cracks. When the mine water is acid and contains compounds such as ferric, copper, or nickel sulphate, corrosion is greatly accelerated. Moisture from warm air passing up the mine shaft and condensing on the wire is another cause. The most important method of protection is the application of the right kind of lubricant when the rope is manufactured. R. A. R.

Inspection of Steel Cables. J. G. Haenel. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Jan., pp. 99–111). [In Portuguese]. Attention is drawn to the necessity of rigorous inspection of steel cables, especially as regards internal corrosion. The more important types of construction of cable are described in relation to uses. The case of a broken cable examined by the Institute of Technological Research is considered.—R. S.

Corrosion of Wet Steel by Hydrogen-Sulphide/Air Mixtures. D. C. Bond and G. A. Marsh. (Corrosion, 1950, vol. 6, Jan., pp. 22–28). An investigation of the corrosion of mild steel strips in H_2S–air mixtures of various concentrations at different temperatures is reported. The conclusions were: (1) The most corrosive mixture was about 1% H_2S in water-saturated air; (2) at H_2S concentrations of about 10%, the corrosion rate increased about 20% when the temperature was raised from 70° to 120° F.; (3) under the conditions applied, the corrosion rate was independent of time, at least during the first several hours' exposure; (4) there was a fairly uniform increase in the amount of sulphide in the products of corrosion with increase in H_2S in the H_2S–air mixture; (5) the oxidation of wet ferrous sulphide was 85·5% complete after 4 hr. exposure to air at 120° F.; and (6) in these experiments the conversion of hydrated iron oxide to iron sulphide (in the presence of H_2S) proceeded faster than the conversion of iron sulphide to iron oxide (in the presence of air).—R. A. R.

The Formulation of Anti-Corrosive Compositions for Ships' Bottoms and Underwater Service on Steel. (British Iron and Steel Research Association, 1950, First Report of Joint Technical Panel N/P2). Earlier work of the Marine Corrosion Sub-Committee of the British Iron and Steel Research Association on anti-corrosive compositions for ships' bottoms has been extended by a study of the effect on performance of: (*a*) Small variations in the pigmentation of two of the most promising formulated compositions already developed, and (*b*) the use of alternative vehicles. Twenty-five main pigmentations bound in each of two media (A) phenol-formaldehyde/stand oil and (B) coumarone/stand oil, were investigated. Three of these pigmentations were also tested when bound in each of five special media, namely E, chlorinated rubber, J1 and J2 dehydrated castor oil modifications of medium (A), and K1 and K2, tung oil modifications of medium A. Raft tests have been made at Caernarvon and Emsworth, and accelerated tests by the Chemical Research Laboratory, Teddington.

The chlorinated rubber medium, E, has again proved to be the best, but the four modifications of the original medium A have each given better results than either of the two media (A and B) in which the full range of pigmentations was studied. There was evidence that an increase in the aluminium content, within the limits used in the tests, improves the protective properties of the compositions. From all points of view, composition No. 655, consisting of a pigmentation of two parts of basic lead sulphate with one part each of aluminium powder, barytes, and Burntisland red bound in medium K1 is the most promising of those studied.

Interim Report of the Departmental Committee on the Deterioration of Cast Iron and Spun Iron Pipes. (Ministry of Health, 1950: H.M. Stationery Office). This is the first interim report of the committee appointed by the Minister of Health in December, 1948, to consider the corrosion of buried cast- and spun-iron pipes. Among the conclusions and recommendations are the following: (1) The environment particularly conducive to pipe failures in England is sulphate-bearing clay, with a high moisture and a low dissolved oxygen content. (2) Sulphate-reducing bacteria, found in nearly all soils, multiply under the anaerobic conditions associated with these clays within a *p*H range of 5·5–9. (3) There is no evidence that the quality of metal used in cast-iron and spun-iron pipes has any bearing on their rapid deterioration, provided it lies within the limits of good commercial practice. (4) In geological formations and conditions known to be corrosive, the normal coating protection of pipes is inadequate. (5) In highly corrosive areas an appreciable expenditure on protective and remedial measures is justified; these measures should be chosen from the following: (*a*) Using a wall thickness greater than the standard; (*b*) the use of flexible joints in conjunction with other protective measures; (*c*) increasing the thickness of protective coatings; (*d*) the use of reinforced bitumen coatings; (*e*) the provision of a 3-in. surround of good quality cement concrete; (*f*) provision of a 12-in. surround of chalk or of suitable granular material; and (*g*) the use of cathodic protection to supplement protective coating, but not as the sole means of protection.—R. A. R.

The Corrosion Resistance of Hard Chromium Deposits. P. Morisset. (Metaux et Corrosion, 1949, vol. 24, Nov., pp. 247–260). Hard chromium deposits prolong the life of a part five to ten times and it is common to credit this to the hard surface. Chromium, however, resists most chemical reagents. It is scarcely attacked, except by hydrochloric acid and the halogen derivatives and is attacked, in certain conditions only, by sulphuric and nitric acids. Resistance to corrosion depends also on the quality, structure, and thickness of the deposit. To give good resistance to corrosion, the deposit must be devoid of porosity, sufficiently thick, and have good adherence.

The author discusses the influence of structure on corrosion resistance and includes some illustrations of the network of cracks in hard chromium deposits revealed by electrolytic polishing and various chemical attacks. The relationships between corrosion resistance and hardness, hydrogen content, surface condition before plating, and treatment subsequent to it, are reviewed. A table is given showing the corrosion resistance of deposits to some 120 media, including organic reagents and industrial mixtures. Finally, industrial applications of hard chromium plating are discussed.—R. S.

Corrosion of Ferrous Alloys by Surface Discontinuity. R. Binaghi. (Metaux et Corrosion, 1949, vol. 24, Sept., pp. 216–222). The author presents data confirming his earlier work and theories in 1913, especially regarding the necessity of a low carbon content for combating corrosion. Hardening increases corrosion by the formation of a finer grain structure, according to many studies, but the author gives data to show that 80% of the hardened constructional steel samples show greater resistance to corrosion than the annealed samples. All the author's specimens underwent tensile and transverse fracture tests so that in every case corrosion would have been subject to various influences owing to abnormal conditions of grain orientation, grain deformation beyond the elastic limit, and irregularity of surface.

Finally, the relationship between corrosion and time is based on the initial humidity of the air which remained confined at the beginning of the experiment because a thin, invisible layer of water was formed on the specimen, causing initial corrosion. Oxygen acts as an anodic depolarizer of the hydrogen, *i.e.*, as a passivator and protector, thus limiting or even arresting corrosion. Longer exposure would not have changed the state of corrosion of the samples. The author believes that it is not sufficient to provide polished surfaces, but that every effort must be made to produce steels with low carbon contents, of uniform micrographic structure, and to provide surfaces as continuous as possible.—R. S.

Electrochemical Activity of Rust Films and the Corrosion of Iron by Rust in an Aerated Humid Medium Approaching Neutrality. E. Herzog. (Metaux et Corrosion, 1949, vol. 24, May, pp. 119–134). A study is made of cells consisting of rusty mild-steel electrodes and non-rusted steel in various electrolytes, with resistivities from 120,000 to 5 ohms/cu. cm. The action of rust was studied from the following angles: (*a*) Theory of the oxygen differential; (*b*) chemical theory; and (*c*) theory of cells consisting of iron oxide and iron.

Measurements of e.m.f. and output of these cells shows that rust acts as a cathode to the surface of the iron. In the absence of oxygen, iron oxide forms a couple with iron, and in the presence of oxygen, rust activates the corrosion of iron not only by a couple effect, but also as an energetic catalyst of depolarization, *i.e.*, of the combination of oxygen with the hydrogen adsorbed at the cathodes.

This cathodic activity of the products of the corrosion of iron is a cause of corrosion additional to the oxygen differential and greatly contributes to the chemical change of the iron in contact with water and air. The iron is anodic beneath the rust, since the access of oxygen is retarded by its retention by the iron oxide. The oxygen combines rapidly with the hydrogen emanating from the action of the cell.

The beginning of corrosion is due to the differences in oxygen content of the uncoated and the oxide-coated parts, *i.e.*, to the formation of local cells, known as the 'Evans effect.' At a later stage, corrosion is due to cathodic effects associated with iron oxide and oxygen.

The author was able to confirm Faraday's law of the electrochemical equivalent by comparing the measured current of the iron-oxide/iron cell with that calculated by the loss in weight of the rusted electrode.

The output of these cells varies particularly with the degree of aeration and the adherence of the products of corrosion. Thus, surface drying considerably increases output by absorption of oxygen and improving the adherence of the oxide film to the iron.

The activity of oxide films varies according to their method of formation, adherence, and porosity. Outputs obtained with a smooth and adherent rust formed by atmospheric action are higher than those of a spongy, less adherent rust formed by water. The currents and e.m.f. obtained are additive.

The resistivity of the electrolyte has less effect. With an initial internal resistance of a rusty-iron/iron cell of the order of 1 ohm/sq. cm. of surface, approximate distance 0·3 to 0·5 mm., outputs vary in the proportion of 1 to 2 in the electrolytes with resistances varying from 10,000 to 1 (distilled water–water with 3% NaCl). This range of values is found even in strongly resistive electrolytes such as distilled water when a certain quantity of soluble and insoluble corrosion products of iron markedly lowers the resistivity of the liquid layer in the immediate vicinity of the surface of the iron.—R. S.

Electrochemical Measures of the Corrodibility of Ferrous Alloys. L. Cavallaro and A. Indelli. (Metaux et Corrosion, 1949, vol. 24, June, pp. 149–156). By their very nature, accelerated corrosion tests imply a distortion of natural conditions. The relative brevity of these tests cannot be obtained by a proportionate increase in the intensity of the various factors promoting corrosion. The depolarizing activity of oxygen, for instance, which is frequently the factor controlling the rate of attack, cannot be increased above a certain limit. Electrochemical methods permit the specific effects of various factors to be measured simultaneously, but they have the disadvantage that the data obtained are not quantitative. Appropriate interpretation of these data is often difficult due to the imperfect knowledge of the function connecting these values with the mechanism of corrosion. Electrochemical results are nevertheless a valuable complement of the analysis of corrosion by standard methods.

The authors describe a series of tests carried out in 1942 with a corrosion cell containing the specimen in the corrosive medium and using a platinum cathode and an Armco iron electrode for short circuiting. Results are described for a series of pre-corroded stainless steel specimens. For each steel and for a given electrolyte, there was a limit of concentration above which the steel was attacked. No such limits were found for iron or for common steels which frequently were more corroded by pure water than by salt solutions. The action of inhibitors in galvanic corrosion is discussed and the importance of conditions of surface defence in relation to electrochemical measurements is explained.—R. S.

Spray Testing with Natural and Synthetic Sea Water. Part II—A Study of Organic Coatings. A. L. Alexander and T. P. May. (American Society for Testing Materials, 1950,

Preprint No. 26). Experiments were conducted with a variety of organic coatings applied to several metals. These were exposed simultaneously to the spray of natural and synthetic sea water and 3% and 20% sodium chloride solutions. The results indicated that it is justifiable to use synthetic sea water in lieu of genuine sea water in salt-spray testing. In long-term tests sea water appeared to be slightly more detrimental than the synthetic product. In evaluating organic coatings on ferrous metals, 3% brine was the most severe of the solutions tested.—R. A. R.

The Corrosion of Steel and Its Protective Metallic Coatings. A. B. Dove. (Mordica Lecture: Wire and Wire Products, 1950, vol. 25, Jan., pp. 29–37, 88–91). Some early observations on the corrosion of metals are recalled, including those of Galvani and the British Admiralty in 1763, and some outstanding reports in the literature after 1900 are referred to. Coating processes are then reviewed, including metal spraying with the Schoop pistol and many plating methods. Finally, the difficulty of hot-dip coating steel with aluminium is pointed out and some tests comparing the resistances of aluminium and zinc coatings are mentioned.—R. A. R.

The Importance of Paint Damage in Protection against Corrosion. K. Würth. (Werkstoffe und Korrosion, 1950, vol. 1, Jan., pp. 20–26). The requirements that a good paint should fulfil are pointed out and the preparation of the metal surface, paint compositions, permeability to moisture and gases, and possible causes of failure are discussed. Damage to paint and subsequent corrosion of the metal underneath are generally due to a combination of several causes. The importance of photographs in reports on damage is emphasized.
R. A. R.

Corrosion Resistance of Copper-Bearing Steels and the Passivity Theory of Wulff and Uhlig. K. Werny and R. Eschelbach. (Werkstoffe und Korrosion, 1950, vol. 1, Jan., pp. 16–20). The results of corrosion tests on copper-bearing steels are reviewed, and it is shown that additions of copper to steel have an effect in accordance with the passivity theory of Wulff and Uhlig. The corrosion resistance of copper-bearing steel is compared with that of other alloy steels and several applications are discussed; its resistance to flue gases up to 450° C. is very good, and a high phosphorus content improves its resistance to ordinary atmospheric corrosion.
R. A. R.

Stress-Corrosion Tests on Turbo-Supercharger Materials in the Products of Combustion of Leaded Gasoline. G. B. Wilkes, jun. (American Society for Testing Materials, 1950, Preprint No. 60). Stress-corrosion tests were made on non-ferrous alloys, high-alloy chromium–nickel–molybdenum steels (two with cobalt), and three stainless steels at high constant temperatures and at fluctuating temperatures. The products of combustion of leaded petrol were somewhat corrosive with fluctuating temperature but not at constant temperature. Tests at constant temperature indicate that, in a long test, PbO with 3% of oxygen becomes less effective in reducing the strength of the alloys than air alone.—R. A. R.

Soil-Corrosion Studies, 1946: Ferrous Metals and Alloys. I. A. Denison and M. Romanoff. (Journal of Research of the National Bureau of Standards, 1950, vol. 44, Jan., pp. 47–76). This report contains the results of measurements of corrosion made on a variety of wrought and cast ferrous materials after exposure to different soil conditions for periods up to 14 years. The compositions of the steels ranged from fractional percentages of nickel and chromium to the high concentrations typical of wholly austenitic steels. In those soils in which there was a significant difference in the pitting of cast iron and wrought materials, cast iron usually pitted at somewhat higher rates. Sustained high rates of corrosion occurred generally in poorly aerated soils high in soluble salts or in acidity. In well-aerated soils low in soluble salts, corrosion virtually ceased after a relatively short period because of the formation of layers of corrosion products close to the metal surface.—R. A. R.

Chemical Aspects of Underground Corrosion and Corrosion Prevention. I. A. Denison. (Proceedings of the American Gas Association, 1948, pp. 517–533). Factors affecting the behaviour of buried ferrous and non-ferrous metals and alloys, especially environment and composition of the materials are considered and studies with a special cell are reported. The essential feature of the development of pits in iron and steel in soils is the formation of a tubercle which excludes oxygen from the pit, thereby allowing the pit to deepen until its contents become saturated with ferrous ions. The most serious corrosion was observed in poorly aerated soils. High concentrations of soluble salts are very corrosive, but only when accompanied by deficient aeration. High contents of chromium in steel may so concentrate corrosion in local areas that deep pitting results.—R. A. R.

Practical Cathodic Protection for Gas Distribution Systems. A. D. Simpson, jun. (Proceedings of the American Gas Association, 1949, pp. 641–668). An account is given of the results obtained and costs incurred by installing cathodic protection on a number of buried steel gas mains in Texas. Full details of the zinc and magnesium anodes and methods of connection are shown in diagrams. Magnesium alloy anodes are used to protect pipe with poor coatings and pipe in soils of high resistance; on new and well-coated pipe, zinc is used because of the small current requirement and the long life desired from the anode.—R. A. R.

Rectifiers and Galvanic Anodes for Cathodic Protection. A. L. Stegner. (Proceedings of the American Gas Association, 1949, pp. 669–673). Factors governing the choice between rectifiers and galvanic anodes for the cathodic protection of buried pipelines are discussed and some successful applications of each are described as well as an installation combining a rectifier and an anode at the far end away from the rectifier.
R. A. R.

ANALYSIS

Magnesium in Iron Determined by Mercury Cathode Method. A. E. LaRochelle and J. A. Fournier. (American Foundryman, 1950, vol. 17, Jan., pp. 65–66). In the making of nodular cast iron by inoculation with magnesium it is necessary to estimate within narrow limits the true value of the retained magnesium. A procedure for this, developed by the Department of Mines and Resources, Ottawa, is described in detail.
R. A. R.

Spectrometric Determination of Carbon in Steels. R. Breckpot and C. Gobert. (Bulletin des Sociétés Chimiques Belges, 1950, vol. 59, Jan.–Feb., pp. 102–106). An almost instantaneous determination of carbon in steels can be achieved with the CIII 2296·86 Å. radiation using electron multipliers sensitive to that wavelength. A quartz spectrograph of average dispersion and an interrupted spark were used; the best results were obtained with a silver or aluminium counter electrode. The results are reproducible to ± 0·008% and the effect of atmospheric CO_2 is negligible.—R. F. F.

Quantitative Analysis of Molybdenum in Steels. Visual Colorimetric Method. F. de Ibarra Landa. (Instituto del Hierro y del Acero, 1950, vol. 3, Jan.–Mar., pp. 39–42). [In Spanish]. The method described enables the quantitative determination of molybdenum to be made in a few minutes and with sufficient accuracy for routine work. No special apparatus is required.

In view of the difficulty of accurately determining percentages above 0·60% molybdenum, the method is arranged to cover three classes of steel: (*a*) very low molybdenum contents; (*b*) 0·12 to 0·34%; and (*c*) 0·40 to 0·60%.—R. S.

Spectrographic Methods for Determining Magnesium in Nodular Iron. F. R. Bryan, G. A. Nahstoll and H. D. Veldhuis. (A.S.T.M. Bulletin, 1949, Dec., pp. 69–72). The procedure described consists of two parts: First, a spectrographic solution method of analysing metal rods to be used as standards for the control analysis; and, second, a technique for determining magnesium as a part of the customary spectrographic analysis of cast-iron rods or pins. It is suggested that average deviations of ± 10% and less of the amount of magnesium present are adequate for routine control purposes; data obtained gives results well within this figure.—J. C. R.

Report of the Committee of Standardisation of Methods of Analysis of the Spanish Iron and Steel Institute, November, 1948. (Tecnica Metalurgica, 1949, vol. 5, July, pp. 266–269). [In Spanish]. The present article reviews the work of the committee on the determination of phosphorus. The methods suggested are all based on the separation of phosphorus as phosphomolybdate. The gravimetric method is described in relation to nickel, chromium–nickel, chromium–vanadium steels (without wolfram), and for high-speed wolfram and vanadium steels. The volumetric method is described for

stainless steels (excluding wolfram and vanadium), for chromium–vanadium steels without wolfram, and for high-speed steels with wolfram and vanadium.—R. S.

Determination of Branches of the Curve of Thermal Decomposition of the Neutral Sulphate of Trivalent Iron to Fix Convenient Temperature Zones in the Gravimetric Analysis of Trivalent Iron in the State $(SO_4)_3Fe_2$. Extremely Sensitive New Reagent for the Trivalent Iron Ion. (Application of Sulphites and Sulphates in Chemical Analysis). IX. T. Gaspar y Arnal and J. M. Liceaga. (Anales de la Real Sociedad Española de Fisica y Química, 1949, vol. 45(B), Dec., pp. 1513–1526). [In Spanish]. A convenient and practically constant composition zone was found in the thermal decomposition of neutral ferric sulphate, between 350° and 400° C., for the exact gravimetric determination of iron. Sodium sulphite dissolved in hydro-alcoholic media is suggested as a sensitive reagent for the trivalent iron ion. Precipitation must be effected in a water bath at 40° to 50° C.

The sensitivity of the reaction may be given as: in aqueous medium $-1{\cdot}2 \times 10^{-6}$ and in hydro-alcoholic medium $-5{\cdot}8 \times 10^{-7}$ per c.c.

The sensitivity is not affected to any appreciable degree by the presence of ammonium salts.—R. S.

The Importance of Standardization of Methods of Analysis in the Metallurgical Industry of Brazil. V. Maffei. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, Jan., pp. 5–15). [In Portuguese]. A critical study is made of the main methods for analysing raw materials and finished products used by the Belgo Mineira Metallurgical Co. of Minas Geraes, and the question of standardizing the best methods with a view to avoiding variation in results is considered. Among the methods referred to are the Volhard method for manganese ores and the $KMnO_4$ and $K_2Cr_2O_7$ methods for iron ores. Details of differences in the results of manganese determinations from the same ore analysed by different laboratories are given. Analytical procedures for pig iron, coke, blast-furnace slag, and refractories are briefly referred to.—R. S.

Handbook on Coal Sampling. N. H. Snyder. (United States Bureau of Mines, 1950, Revision of Technical Paper 133). This paper has been prepared primarily for the use of U.S. Government employees charged with the duty of sampling coal purchased by the Government. The steps necessary to obtain representative samples of coal for analysis are described in detail.—R. A. R.

Danger from Chemicals in the Laboratory. M. van Arsdell. (Metalurgia y Electricidad, 1950, vol. 14, Jan., pp. 41–45). [In Spanish]. The effects of the various chemical products are classified according to their type of toxicity. The article deals with the effect and treatment of alkalis, cations, anions, cyanides, halogens, nitrates, sulphides and sulphates, and oxalates, and gives a list of general rules.—R. S.

HISTORICAL

Iron and Man. B. Corrêa de Mattos Netto. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, Oct., pp. 413–434). [In Portuguese]. The author, before dealing with Brazil, surveys the history of ironmaking throughout the world. He traces the explorations of De Souza in colonial days on behalf of Phillip I and II of Portugal. The discovery of gold, silver, and iron in Brazil was first announced by Anchieta in 1554. Some early Brazilian iron installations are mentioned and the story continues through the XIXth century with the development of the Minas Geraes region. The article constitutes a concise account of the iron industry's historical development in Brazil.—R. S.

Milestones in Metallurgy—Some Outstanding Developments. G. H. Stanley. (Annual Proceedings of the Associated Scientific and Technical Societies of South Africa, 1946/47, Reprint). This survey of outstanding metallurgical developments is divided into eight 'milestones.' Under the first are cited smelting and melting processes such as the wrought iron column at Delhi (about A.D. 400). The second is the introduction of hot blast by J. B. Neilson. The third is the invention of the Bessemer process of blowing. The fourth relates to metallography. The fifth deals with aluminium production, the sixth with the cyanide process of gold extraction, the seventh with froth flotation, and the last with the development of alloy steels.—R. A. R.

Czech Historical Artistic Castings. (Hutnické Listy, 1949, vol. 4, May–Dec., Supplements). These supplements present a series of 71 illustrations of ornamental castings, mainly tombstones and monuments, of the XVIIIth and XIXth centuries.—R. A. R.

Floris Osmond and the Allotropy of Iron. Beta Iron, Ferronite and the Great Allotropist. N. T. Belaiew. (Metaux et Corrosion, 1949, vol. 24, Oct., pp. 231–234). In his recent contributions to the study of the allotropy of iron, Carl Benedicks, first recipient of the Floris Osmond medal, insists on the fact, already indicated by Osmond, that allotropic transformations are, in part, continuous. In particular, the contraction of iron between 770° and 900° C. (in the β-iron region of Osmond) depends on the $\alpha \rightarrow \gamma$ transformation being partly continuous, without admitting a change of phase. According to Benedicks, β-iron would be an α-iron containing in solution a certain quantity of atoms characteristic of γ-iron. Thus, Benedicks proposed a clear distinction between the ferrite of α-iron and the "ferrite" of β-iron. He proposed to call the latter "ferronite" to indicate its close resemblance to ferrite, though its carbon content distinguished it clearly from the latter.

The co-operation between Osmond and Tschernoff on the transformation points is reviewed. At first, Osmond considered that the phenomena associated with the A_2 and A_3 points had not been sufficiently studied to justify a hypothesis of three modifications of iron. In 1896, however, in his communication to The Iron and Steel Institute regarding the research of Henry Marion Howe, Osmond decided to recognize the three modifications of alpha, beta, and gamma iron.

Some reference is also made to Osmond's literary work, including the Latin poem "Ferrum."—R. S.

Floris Osmond. The Man and His Work. A. Portevin. (Metaux et Corrosion, 1949, vol. 24, Oct., pp. 223–230). The centenary of the birth of Floris Osmond, creator of metallography, was commemorated on the 7th October, 1949, by the Société Française de Métallurgie. This article consists of extracts from M. Portevin's speech. Since Osmond led a solitary life, leaving no family or memoires, the account is based on letters preserved by friends and on part of Osmond's publications.

After gaining some industrial experience at Denain-Anzin and, later, at Le Creusot, Osmond quit the industrial atmosphere in favour of that of his laboratories at the Sorbonne. His first paper on the cellular structure of steel appeared in 1885. Besides his development of the microscopical examination of steel, he worked on thermal analysis and discovered the transformation points by revealing the thermal and magnetic anomalies accompanying them. His main theme was to superimpose the notion of structural equilibrium on the chemical theory. He studied crystal deformation to seek the origin of mechanical properties. His discovery of the allotropy of iron was the king post of his attempts to explain the phenomena of hardening.

In following his passion for pure research, untrammelled by financial obligations, Osmond deprived himself of the great advantages of an industrial laboratory, but his intellectual capacities outweighed such disadvantage.

When Le Chatelier attempted to standardize the names of the constituents, Osmond opposed him, feeling that the delicate nuances should be preserved.

The three main parts of Osmond's character were disinterested love of science, absolute independence of thought, and the wide extent of his scientific knowledge.—R. S.

ECONOMICS AND STATISTICS

Modernization of the French Metallurgical Industry. M. Piens. (Tecnica Metalurgica, 1949, vol. 5, Aug.–Sept., pp. 289–297). [In Spanish]. The author summarizes the plans and achievements of the French iron and steel industry up to May, 1949. He first discusses pre-war equipment and production and sources of raw material available to the French industry. The labour position is examined, and the author outlines the French Government's modernization plan for the rehabilitation of plants and the production of, first, 10 million tons, and, ultimately, 15 million tons of steel with 3·7 million tons of castings per annum. Finally, the professional and commercial organization of the industry is explained with some notes on the financing of the plan. R. S.

State and Outlook of the Argentine Metallurgical Industry. (Industria y Química, 1949, vol. 11, Oct., pp. 33–34). [In

Spanish]. This is an extract of the article by the President of the Chamber of Metallurgical Industries published in the Review "Comments on Argentine Trade" of the U.S. Department of Commerce. It gives an account of the dangers of the situation of the metallurgical industry in Argentina; the raw-material situation; cost of labour; and import regulations and customs duties.—R. S.

Survey of the Metallurgical Industry in Minas Geraes [Brazil]. A. Lanari, jun. (Boletim da Associação Brasileira de Metais, 1946, vol. 2, Oct., pp. 13–36). [In Portuguese]. Owing to the lack of finishing and fabricating industries, the output of the blast-furnaces exceeds many times the national demand for pig iron. Added to this, the freight and costs of finished and semi-finished products are extremely high. In view of the high freight on pig iron, it is more economical for the consumers of São Paulo to import iron ore from Minas Geraes for local reduction than to obtain the pig iron from there.

The author discusses in detail the production and consumption of iron in Minas and the proportion of Minas Geraes ore which is transformed into iron outside the State. Of the Minas ore 80% is exported to feed outside industries. The dependence of Minas Geraes on São Paulo for the consumption of its ore output as well as for its own semi-finished products is a serious threat to the existence of the mining and metallurgical industry in the State. Rising labour costs and the increasing gap between the freights on ore and on pig iron add to the difficulty. The industry must increase the output per man-hour. The strangling tariff system must be overhauled and the internal market for Minas pig iron must be expanded.—R. S.

Mainly About Steel. A. Roebuck. (Journal of the Junior Institution of Engineers, 1950, vol. 60, pp. 138–152). The author gives a sketch of the organization, control, methods of production, and achievements of the iron and steel industry of Great Britain; notes on research and education are included.

Atomic Energy and Its Application in Time of Peace—Experimental Reactors. L. Biernacki. (Przeglad Techniczny, 1949, May–June, pp. 137–146). [In Polish]. The application of isotopes in chemistry, metallurgy, biology, and medicine is discussed. Some applications of the isotopes C^{14}, S^{35}, and P^{32} in metallurgy for structural and chemical analysis are given.—W. J. W.

MISCELLANEOUS

The Geiger-Müller Counter. L. F. Curtiss. (National Bureau of Standards, 1950, Jan., Circular 490). This 25-page circular has been issued to provide information on the nature, construction, and use of Geiger-Müller counters. It is in eight parts, as follows: (1) Introduction; (2) the Geiger-Müller counter; (3) special forms of the Geiger-Müller counter; (4) methods of detecting counter pulses; (5) applications of counters to quantitative measures; (6) proportional counters; (7) preparation and filling of Geiger-Müller counters; and (8) bibliography.—R. A. R.

Economical Inert Gases Serve Industry in Many Ways. E. J. Funk, jun. (Industrial Heating, 1950, vol. 7, Jan., pp. 58–70; Feb., pp. 242–248, 260). The production and uses of inert gases are discussed. The applications dealt with in Part I include preventing decarburization during the heat-treatment of steel, shielding the arc when welding, and fire-fighting. Part II is concerned with inert gases for food protection and the prevention of the polymerization of paints in storage tanks.—R. A. R.

An Attempt to Define Technical Terms in Metallurgy. J. Mendes França. (Boletim da Associação Brasileira de Metais, 1949, vol. 5, Apr., pp. 211–244). [In Portuguese]. The author attempts to define metallurgical terms as a basis for a technical dictionary to be sponsored by the Brazilian Association of Metals. English, French, and German terms are given against the Portuguese in most cases. The alphabetical order conforms to the Portuguese terms. Two hundred and fifty-five terms are given, and there is a lengthy discussion.

BOOK NOTICES

GAILER, J. W., and E. J. VAUGHAN. "*Protective Coatings for Metals.*" 8vo, pp. xiv + 261. London, 1950: Charles Griffin and Co., Ltd. (Price 24*s.*)

It is probable that most people turning to a book with this title will be more interested in the choice of protective coatings for a given purpose than in the methods by which the coatings are applied. If so, they may be a little disappointed because the main value of this work is that it gives descriptive accounts of a wide range of protective processes for use, not only on iron and steel, but also on the non-ferrous metals, aluminium, magnesium, zinc, and their alloys. It does not give much comparative information regarding the respective merits of individual processes when used for practical purposes, and the reader is often left to judge between them for himself. In other words, comparative test data are missing in most cases. The book gives valuable information, however, as to the nature of many current proprietary protective processes which the authors mention fairly and squarely by name, even though in some cases they run into difficulty. For instance, when on page 91 they write, "Metal spraying, or Metallisation as it is sometimes called . . ." they are in great danger of rendering themselves unpopular with a considerable section of the metal-spraying industry. Other good features of the book are the plentiful references to methods of testing given under each coating process and the tables of the properties of the various coatings given at the end of the volume.

As has been indicated, the weakness of the book lies in the fact that the authors fail to bring much critical faculty to bear on the relative merits of the different types of coating when used for particular purposes. Although they state in the preface that "the subject matter of this book has been gathered from all available sources," there seems to be a surprising number of sources that have escaped them. For example, there is no reference to the published results of tests by the Protective Coatings Sub-Committee of the British Iron and Steel Research Association on protective metallic coatings. Consequently, it may be said, in reply to the authors' suggestion for possible improvements, that the most effective step that could be taken would be to include more information that would help the reader to discriminate between the different protective processes described. Despite its limitations in this respect the authors' work should prove a useful source of reference, particularly in focusing attention on the processes that are in industrial use at the moment and giving particulars of them.

The production of the book by Charles Griffin and Co., Ltd., is of a high standard, in fact this is the best-printed book from these publishers which the present writer has had occasion to read.—J. C. HUDSON.

Corrigenda

In the review of the book "*Welding—Design and Processes*" on p. 167 of the *Journal* for October, 1950, the author's name was given as Hilbert, B. R. This should have been Hilton, B. R.

In the *Journal* for April, 1950, p. 494, the name of the author in the first abstract should have read "M. Meyer."

MAREK, C. T. "*Fundamentals in the Production and Design of Castings.*" 8vo, pp. xi + 383. Illustrated. New York, 1950: John Wiley and Sons Inc.; London: Chapman and Hall, Ltd. (Price 32*s.*)

The principal object of this book is to assist the engineer in the design of castings so that they may be produced efficiently for their purpose and with a minimum of expense in labour and material. Professor Marek has set out in a very lucid manner the fundamental principles involved in the casting of metal to shape, and includes a careful definition of terms in common use in the foundry, so that with the aid of this book an engineer should be able to speak the language of the foundry, and be able not only to make the best use of castings in his engineering structures but also co-operate with the founder in designing castings which are more efficient, easier to make, and in consequence

cheaper. The need for such co-operation between founder and engineer is great.

Emphasis is placed upon the practical foundry operations of sand control, moulding, core-making, and casting rather than upon the physical and metallurgical properties of castings, which are dealt with in a more theoretical manner. The importance of good foundry equipment and of mechanization is duly stressed, and there is a valuable section dealing with the layout of casting production units, so that altogether the book is well worth the attention of those who are responsible for the operation of foundries as well as those who apply their products.—W. C. NEWELL.

WUTTKE, F. "*Die Grauguss-Gasschweissung leicht gemacht!*" 8vo, pp. 90. Illustrated. Halle/Saale, 1950 : Carl Marhold Verlagsbuchhandlung. (Price DM 6.75)

This is a good practical book dealing with oxy-acetylene welding of cast iron, but it is improbable that English readers who might be interested will understand German. It contains little if any theory, but does give exhaustive details of the practical aspects of welding cast iron.

Practical instructions are given for the welding of the body of a hand fly press, of cylinder blocks, cylinder heads, cylinders, machine tool parts, and the like. The author differentiates between welding without preheating, preheating to a dull red heat with two flames, and preheating which consists of heating up the whole piece to be welded.

The practical aspects of welding left to right and right to left as well as many other practical wrinkles are considered in considerable detail. The book is adequately illustrated.—J. FERDINAND KAYSER.

NEW PUBLICATIONS

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS. "*Electric Furnace Steel Conference.*" Proceedings, vol. 7. Pittsburgh Meeting, Dec. 8–10, 1949. 8vo, pp. 334. Illustrated. New York, 1950 : The Institute.

AMERICAN SOCIETY FOR METALS. "*Machining—Theory and Practice.*" Pp. 504. Cleveland, Ohio, 1950 : The Society. (Price $6.50)

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Data on Corrosion- and Heat-Resistant Steels and Alloys—Wrought and Cast.*" Special Technical Publication No. 52-A. 8vo, pp. 79. Philadelphia, 1950 : The Society. (Price $2.50)

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Symposium on Evaluation Tests for Stainless Steels.*" Special Technical Publication No. 93. 8vo, pp. 231. Illustrated. Philadelphia, 1950 : The Society. (Price $2.50)

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Papers on Radiography.*" Special Technical Publication No. 96. 8vo, pp. 95. Illustrated. Philadelphia, 1950 : The Society.

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Symposium on Testing of Cast Iron with SR-4 Type of Gage.*" Special Technical Publication No. 97. 8vo, pp. 92. Illustrated. Philadelphia, 1950 : The Society.

ANGLO-AMERICAN COUNCIL ON PRODUCTIVITY. "*Pressed Metal.*" Report of a visit to the U.S.A. in 1949 of a Productivity Team representing the Pressed Metal Industry. 4to, pp. 52. Illustrated. London, 1950 : The Council. (Price 2*s.* 6*d.*)

ANGLO-AMERICAN COUNCIL ON PRODUCTIVITY. "*Grey Iron-founding.*" Report of a visit to the U.S.A. in 1950 of a Productivity Team representing the Grey Ironfounding Industry. 4to, pp. 125. London, 1950 : The Council. (Price 3*s.* 6*d.*)

APPLE, J. M. "*Plant Layout and Materials Handling.*" 8vo, pp. 367. Illustrated. New York, 1950 : Ronald Press Co. (Price $5)

BRITISH IRON AND STEEL FEDERATION. "*Statistical Year Book for* 1948." Part II. "*Overseas Countries.*" 4to, pp. xvi + 432. London, 1950 : The Federation.

BRITISH IRON AND STEEL FEDERATION. "*Statistical Year Book for* 1949." Part I : "*United Kingdom Statistics.*" 8vo, pp. vii + 114. London, 1950 : The Federation. (Price 7*s.* 6*d.*)

BRITISH STANDARDS INSTITUTION. B.S. 18 : 1950. "*Tensile Testing of Metals.*" 8vo, pp. 19. London : The Institution. (Price 2*s.* 6*d.*)

BRITISH STANDARDS INSTITUTION. B.S. 185 : Part 1 : 1950. "*Glossary of Aeronautical Terms.*" 8vo, pp. 76. London : The Institution. (Price 7*s.* 6*d.*)

BRITISH STANDARDS INSTITUTION. B.S. 240 : Part 2 : 1950. "*Steel Balls for Brinell Hardness Testing.*" 8vo, pp. 7. London : The Institution. (Price 2*s.*)

BRITISH STANDARDS INSTITUTION. B.S. 980 : 1950. "*Steel Tubes for Automobile Purposes.*" 8vo, pp. 23. London, 1950 : The Institution. (Price 2*s.* 6*d.*)

BRITISH STANDARDS INSTITUTION. B.S. 1553 : Part 2 : 1950. "*Graphical Symbols for Power Generating Plant.*" 8vo, pp. 15. London : The Institution. (Price 2*s.* 6*d.*)

BRITISH STANDARDS INSTITUTION. B.S. 1553 : Part 3 : 1950. "*Graphical Symbols for Compressing Plant.*" 8vo, pp. 11. London : The Institution. (Price 2*s.*)

BRITISH STANDARDS INSTITUTION. B.S. 1589 : 1950. "*Thermal Insulating Materials. Plastic Composition. Flexible and Loose-Fill.*" 8vo, pp. 13. London : The Institution. (Price 2*s.*)

BRITISH STANDARDS INSTITUTION. B.S. 1669 : 1950. "*Industrial Perforated Plate.*" 8vo, pp. 10. London : The Institution. (Price 2*s.*)

BURNHAM, T. H., and D. H. BRAMLEY. "*Engineering Economics.*" Book II. "*Foundry Organisation and Management.*" Sixth Edition. London : Sir Isaac Pitman and Sons, Ltd. (Price 15*s.*)

CURTIS, F. W. "*High Frequency Induction Heating.*" Second Edition, pp. 389. New York : McGraw-Hill Book Co., Inc. (Price $6)

EDWARDS, R. S. "*Co-operative Industrial Research.*" London : Sir Isaac Pitman and Sons, Ltd. (Price 20*s.*)

ELEKTRISKA SVETSNINGSAKTIEBOLAGET. "*Tillämpad bågsvetsning. Application of Arc Welding.*" La. 8vo, pp. xvii + 327. Illustrated. Gothenburg, 1950 : Elektriska Svetsningsaktiebolaget. (Price 21*s.*)

"*Fortschritte auf dem Gebiete der Phosphatierung.*" 3. Band. Sammlung von Beiträgen aus dem *Archiv für Metallkunde*, 1948 *und* 1949. Zusammengestellt und herausgegeben von W. Köhler. 8vo, pp. 141. Weinheim/Bergstr. 1950 : Verlag Chemie G.m.b.H. (Price DM 7.80)

GOETZEL, C. G. "*Treatise on Powder Metallurgy.*" Volume II. "*Applied and Physical Powder Metallurgy.*" 8vo, pp. xviii + 910. Illustrated. New York, 1950 : Interscience Publishers Inc. ; London : Interscience Publishers, Ltd. (Price £7 4*s.*)

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LÄTZIG, W. "*Läppen.*" Grundlagen und praktische Anwendung. Sm. 8vo, pp. 185. Munich, 1950 : Carl Hanser Verlag. (Price DM 11.20)

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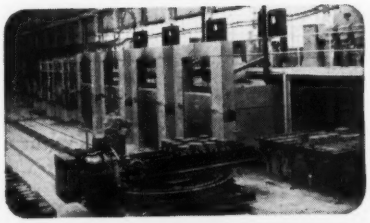

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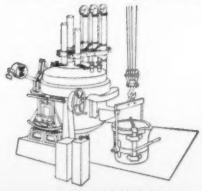

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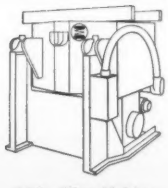

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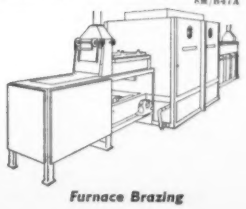

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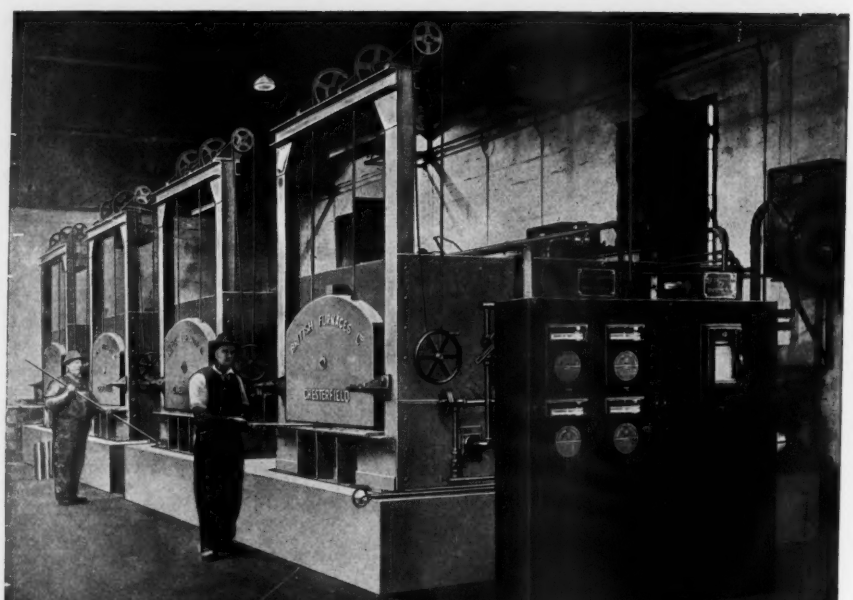

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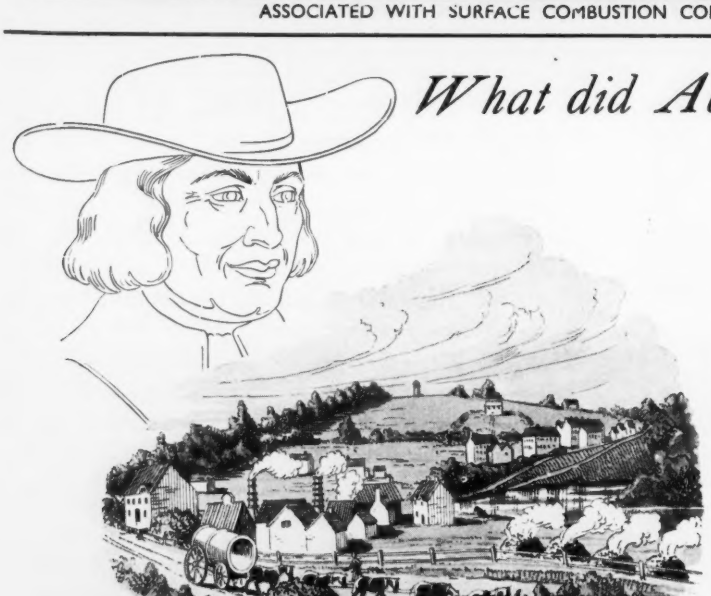

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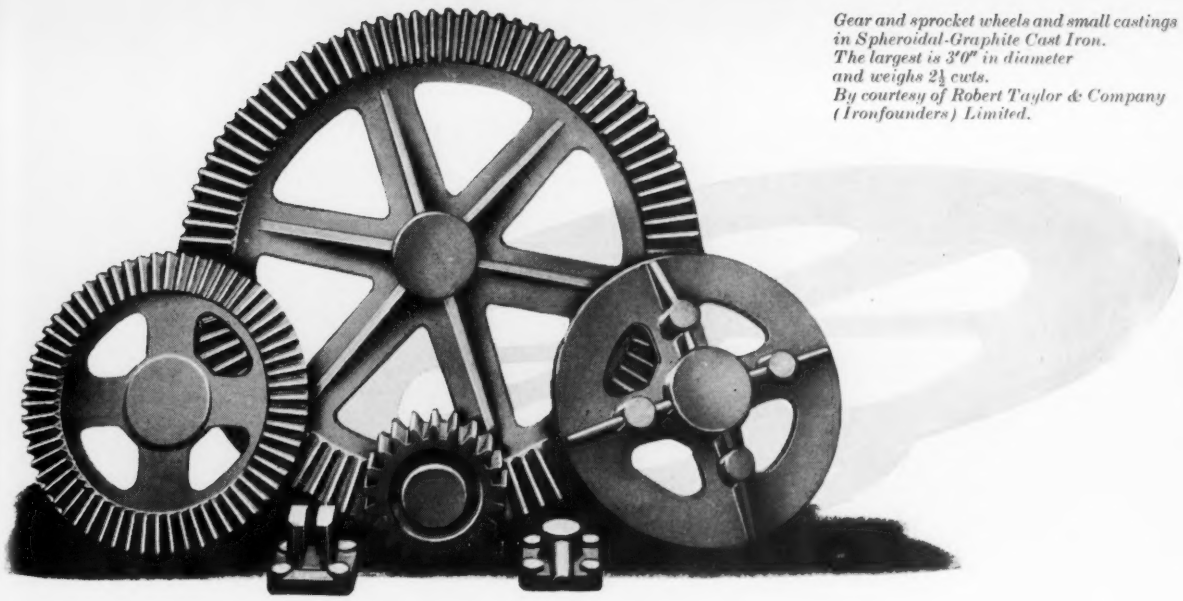

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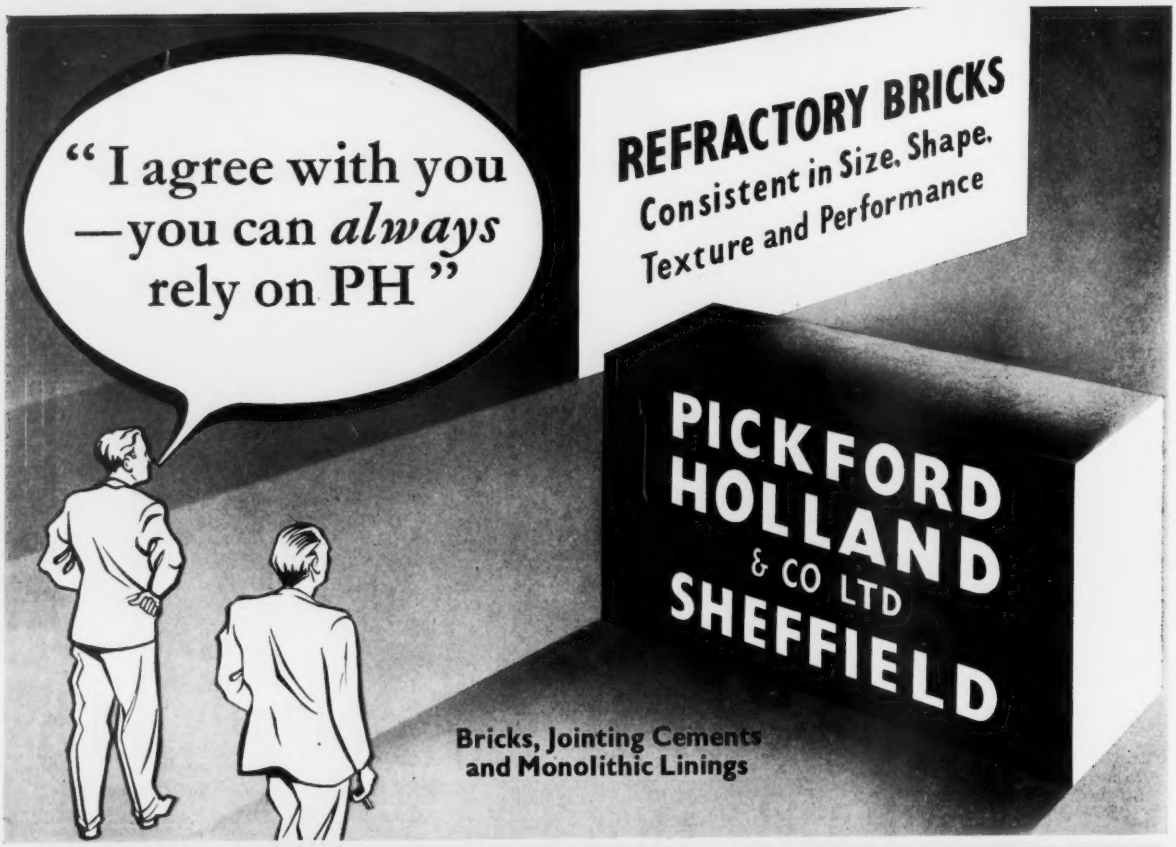
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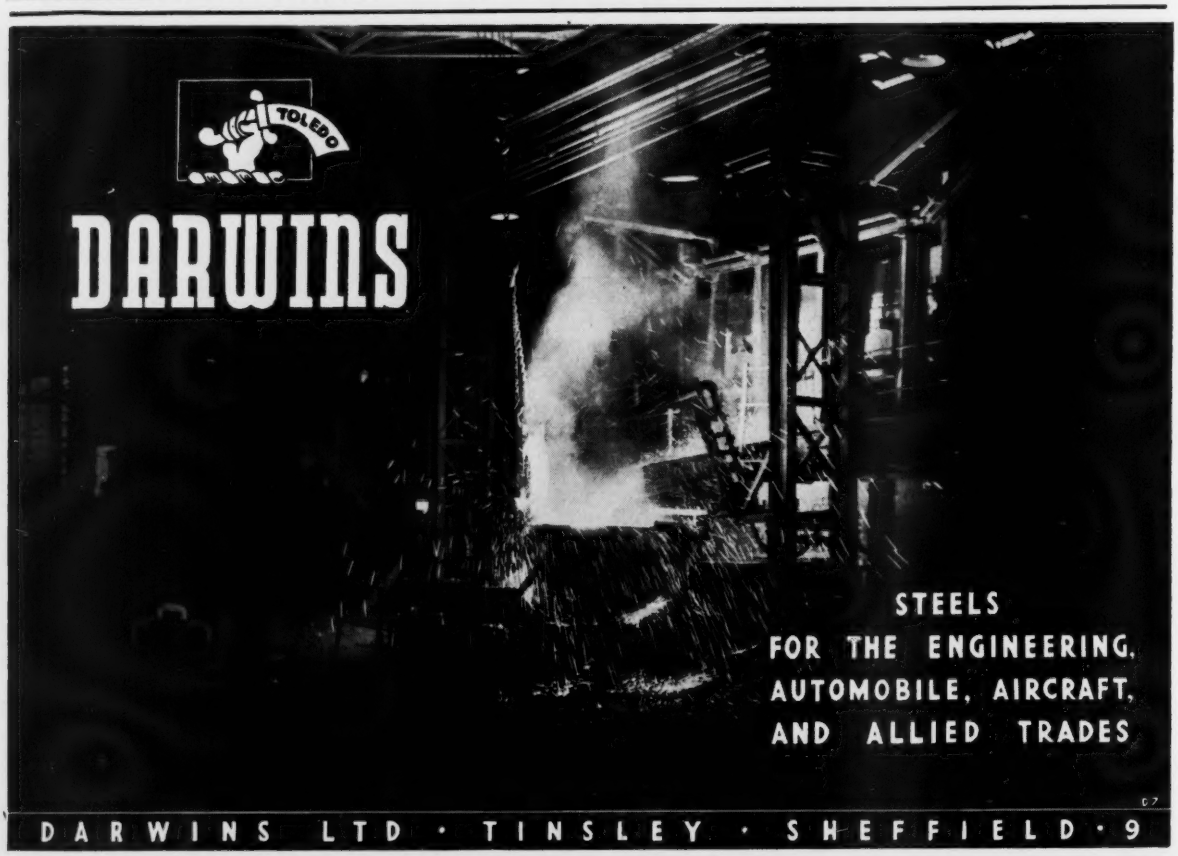
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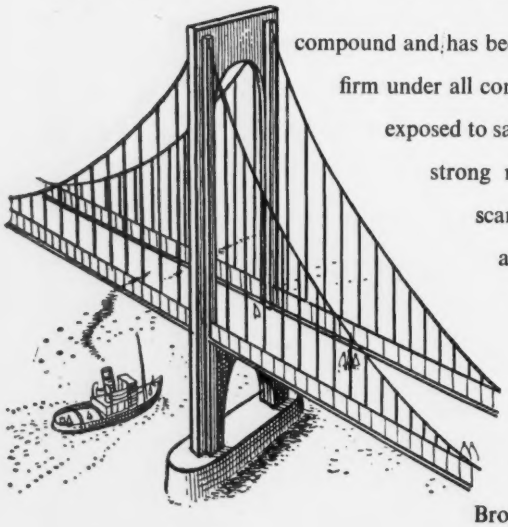

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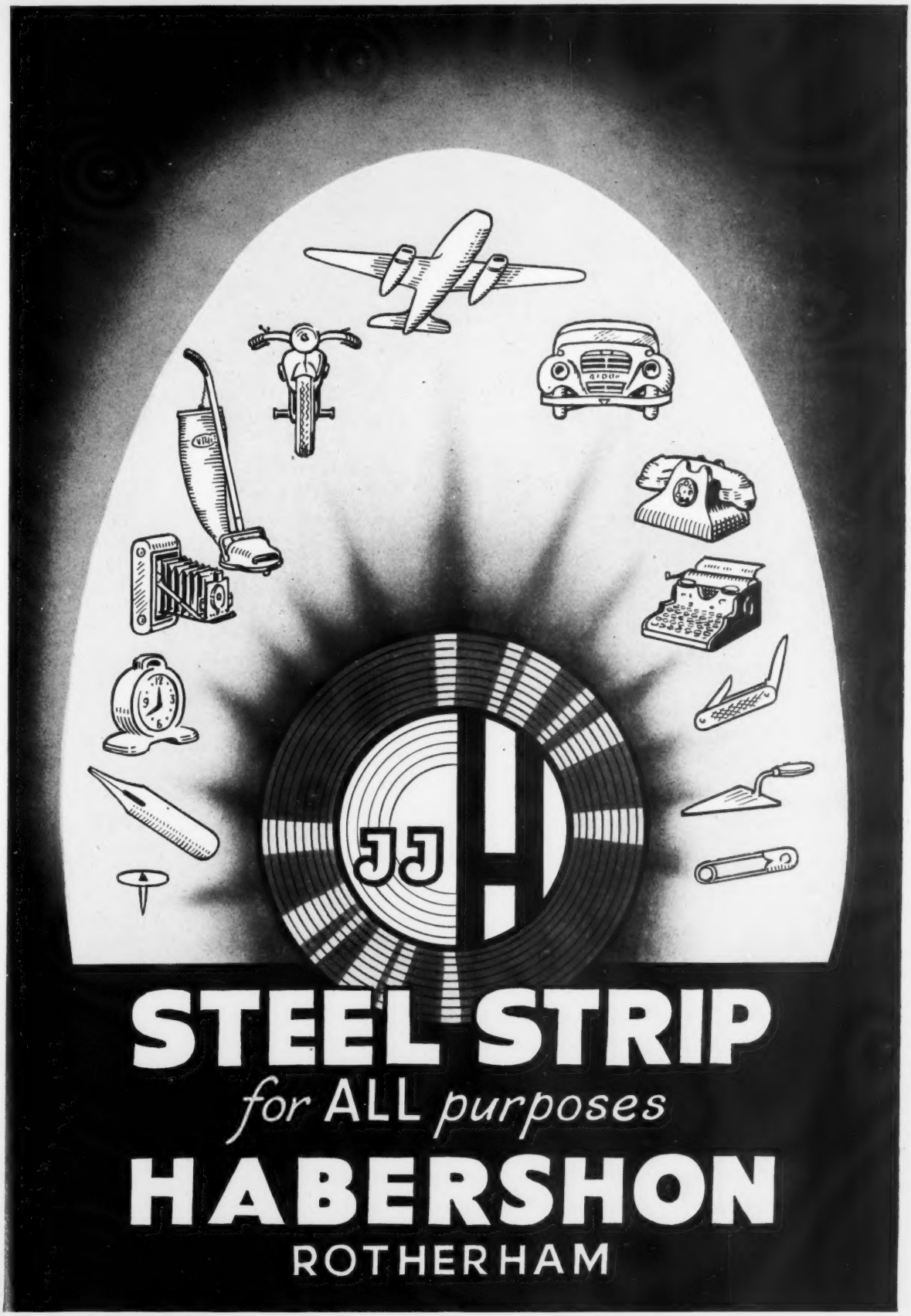
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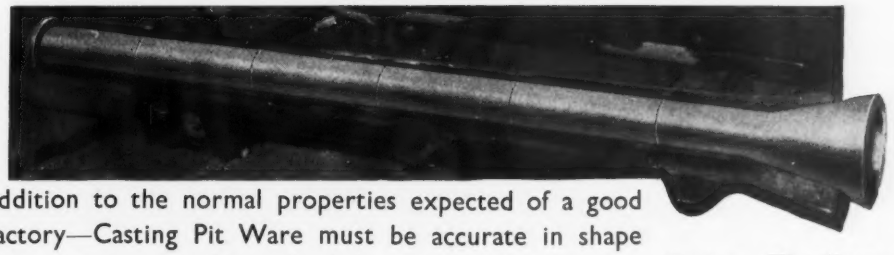

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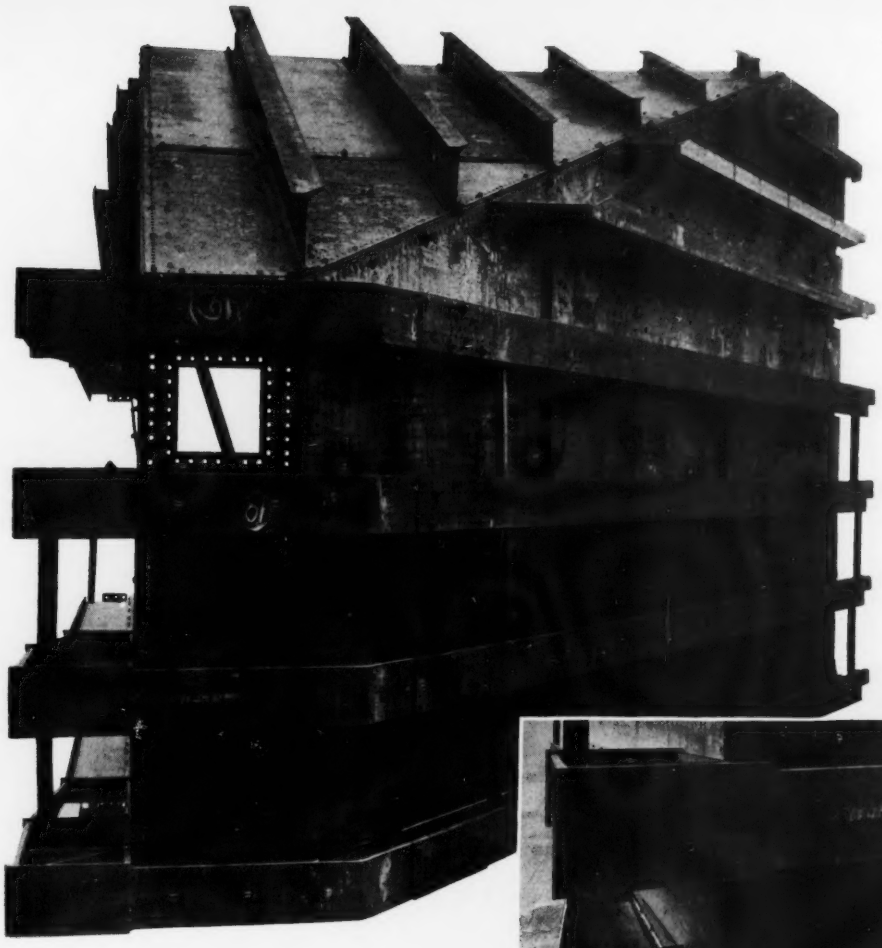

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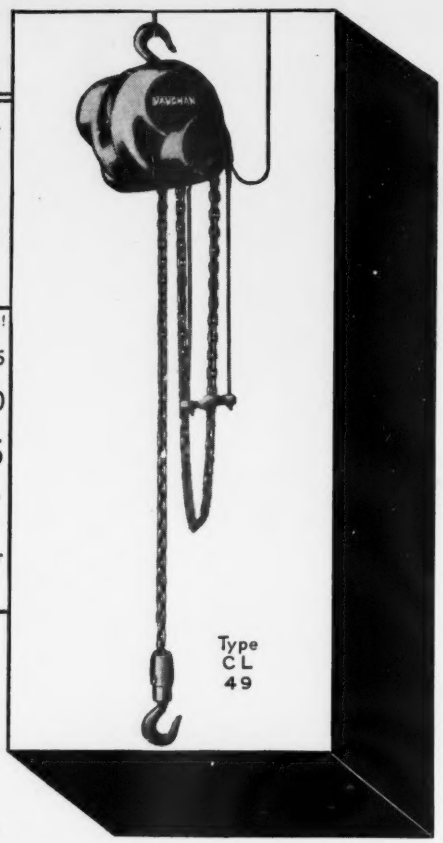

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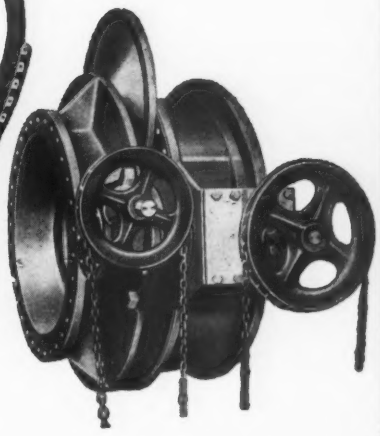

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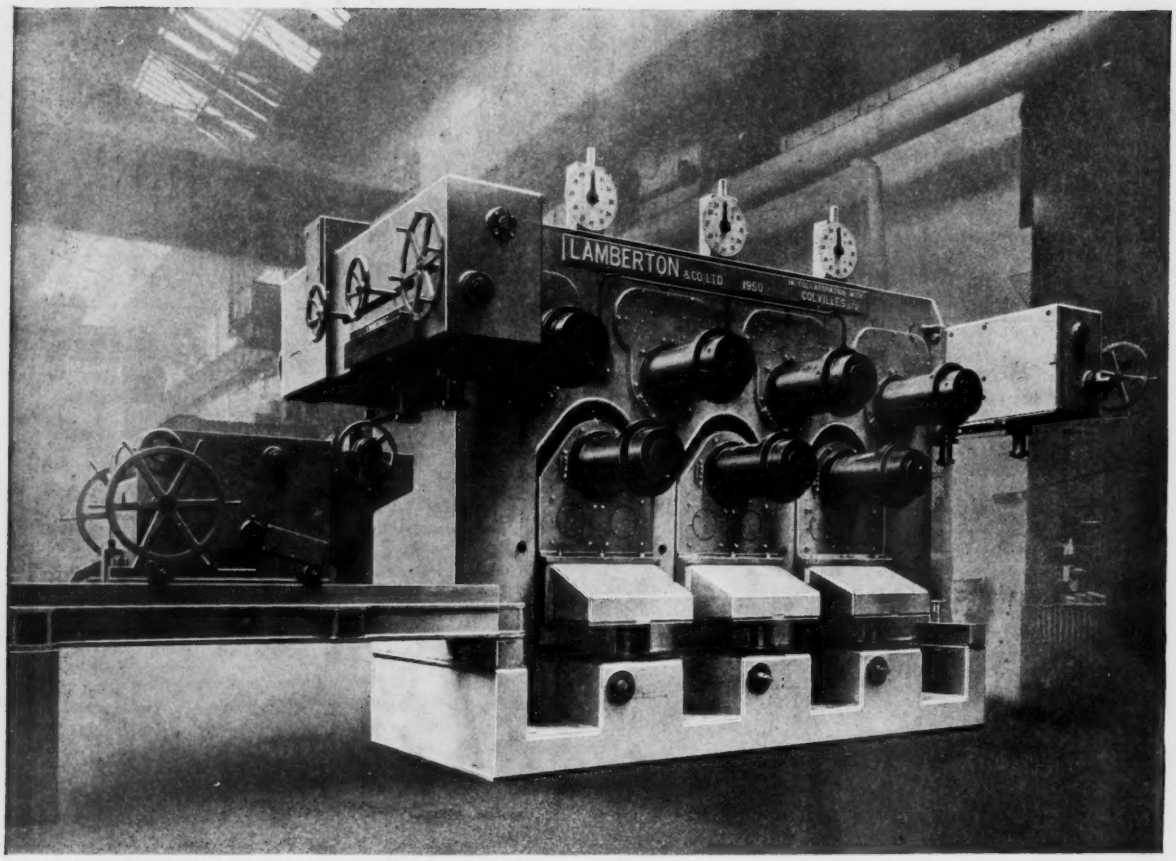

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